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FINAL REPORT

Wintertime Traffic Generated PM_{10} Hot Spots

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Abstract

The Air Quality Group of the Crocker Nuclear Laboratory at UC Davis conducted a study of particulate matter concentrations in the vicinity of the large Sunrise Boulevard/Greenback Lane intersection in Sacramento, CA in winter 1997. The purpose of the study was to look for "Hot Spots" of PM_{10} and $PM_{2.5}$ concentrations due to traffic activity. We collected samples over 19 measurement periods from February 25 through March 7, 1997.

This study followed an earlier UC Davis study of particle "hot spots" at the intersection of Stockton Boulevard and Florin Road in Sacramento, conducted in August, 1995 (UC Davis, 1996). In that study, UC Davis calculated PM_{10} and $PM_{2.5}$ emission rates from the roadway traffic, and concluded that the intersection is not likely to be a "PM_{10} hot spot" unless the background concentrations were already close to the 150 $\mu g/m^3$ federal 24-hour standard. However, the Stockton/Florin intersection was not one of the highest traffic intersections in Sacramento. Furthermore, the Stockton/Florin study was conducted in the summer. Although this corresponded to a very dusty time of year, the daytime mixing was much greater than during the winter. The study reported here was conducted at a high traffic intersection during the winter to capture low wind speeds and mixing heights. It was thought that these conditions might lead to a PM_{10} "hot spot."

The results of this study indicate that the Sunrise Boulevard/Greenback Lane intersection is not a "hot spot" of PM_{10} under the meteorological and traffic conditions measured. High concentrations of PM_{10} mass were observed on March 6, 1997 from 6:45-11:15 p.m. during a period of stagnant wind and a stable surface layer, but they reached only ~75-98 $\mu g/m^3$ at the intersection sites. The highest concentration during that period, 112 $\mu g/m^3$, was recorded at the site farthest from the intersection, implying that the intersection itself was not the major source of particles. Instead, there was a general increase in PM_{10} concentrations throughout the region. This general regional increase is likely caused by largely by vehicular sources, though. The composition of PM_{10} during the period showed reduced contribution from soil and increased contribution from organic matter (as measured by hydrogen). The soot contribution to the total PM_{10} mass was correlated to the organic mass contribution, indicating that the source of organic mass was traffic-related. The contribution from soot was not large, though, so diesel vehicles were only a small factor in the PM_{10} concentrations at this site.

Introduction

Federal conformity rules require that state agencies responsible for approval and/or funding of transportation projects ensure that such projects conform to an approved or promulgated state implementation plan and to all applicable state and federal air quality standards. Because of this, Caltrans needs to know whether "hot spots" of PM_{10} emissions exist at particular roadway configurations in California. If "hot spots" exist, road construction projects might have to mitigate the PM_{10} impacts. In this report, a "hot spot" of particulate matter is a roadway configuration that could lead to a violation of the particulate matter standard at a nearby monitor when the surrounding region is at or below typical concentrations for the area. It is not a "hot spot" if the surrounding region is just below the standard during a pollution episode and the incremental pollution added by the roadway pushes it above the standard at a nearby monitor.

An earlier UC Davis field study indicated that the Florin Road/Stockton Boulevard intersection is unlikely to be a "hot spot" of PM_{10} emissions. The study was conducted during the summer when dust levels were expected to be high due to the long preceding period without rain. Summer is a time of increased vertical mixing and higher wind speeds, though, so that dilution may have reduced the likelihood of PM_{10} "hot spots." The study reported here was designed to investigate whether an even larger intersection might become a PM_{10} "hot spot" during the stable, low wind speed conditions that can occur during winter months.

Methods

We conducted a field study at the intersection of Sunrise Boulevard and Greenback Lane in Sacramento, California beginning at 4:30 p.m. on February 25, 1997, and concluding at 9:30 a.m. on March 7, 1997. This intersection has the third highest 24-hour traffic volume in Sacramento, as shown in Table 1. We used three 10-meter towers to hold meteorological and particulate matter samplers, two in fixed locations and one that we moved occasionally during the study.

Table 1. The ten Sacramento intersections with highest traffic volumes

Intersection Location	24-Hour Traffic Volume
Fair Oaks Blvd. & Watt Ave.	132,380
Fair Oaks Blvd. & Sunrise Blvd.	114,860
Madison Ave. & Sunrise Blvd.	104,190
Coloma Road & Sunrise Blvd.	100,360
Greenback Lane & Sunrise Blvd.	99,620
Folsom Blvd. & Watt Ave.	98,980
Sunrise Blvd. & Zinfandel Drive	93,850
Gold Expressway & Sunrise Blvd.	90,470
Garfield Ave. & Greenback Lane	90,200
Auburn Blvd & Watt Ave.	89,780

Sampling site configuration

Figure 1 shows a schematic diagram of the Sunrise/Greenback intersection and the locations of our samplers. We set up fixed sites with 10-meter towers at the NE corner and SW far sites (dark gray in Figure 1) for meteorological and particulate matter measurements. We used our mobile hydraulic tower at the NE far, SW corner, and SE corner locations (light gray) for particulate matter measurements only. For each test, one of the three mobile locations was used in conjunction with the two fixed locations.

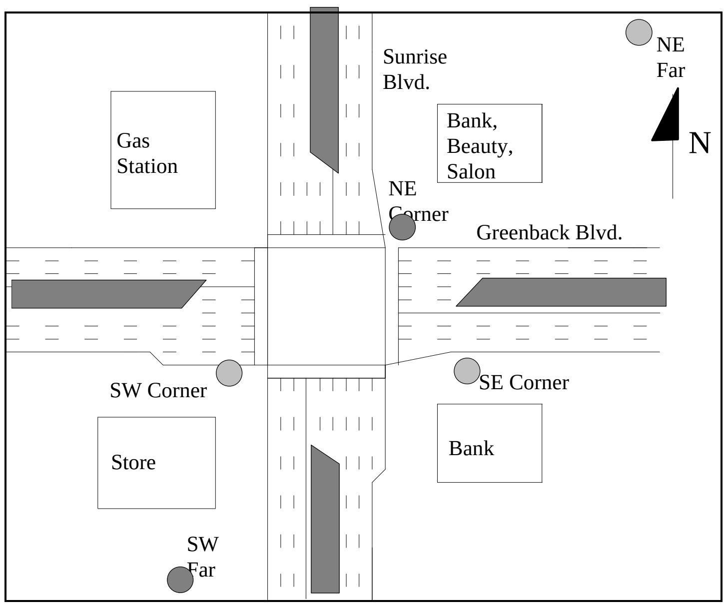

Figure 1. Sunrise/Greenback intersection configuration with location of sampling sites

The sampling site locations are shown in Table 2 relative to the center of the intersection. The roadway dimensions are also shown. The NE Corner site was closest to the roadway at three meters north of Greenback lane and one meter east of Sunrise Boulevard.

Particulate matter measurements

We measured particles in the PM_{10} and $PM_{2.5}$ size ranges using modified IMPROVE samplers (Eldred, 1988). The PM_{10} version of this sampler uses a Sierra-Anderson size-selective inlet to collect particles smaller than 10µm aerodynamic diameter. The $PM_{2.5}$ sampler uses a cyclone of the AIHL design to select particles smaller than 2.5µm aerodynamic diameter. Figure 2 shows a diagram of the $PM_{2.5}$ IMPROVE sampler; the PM_{10} sampler is similar. We collected PM_{10} samples on 25mm Teflon filters at heights of 1m, 3m, and 9m; $PM_{2.5}$ samples were collected at heights of 3m and 9m. All five measurements were taken at every sampling location.

Sample analysis

We analyzed the Teflon filters from the modified IMPROVE samplers gravimetrically for total mass collected, and obtained the mass concentration by dividing the mass collected by the volume of air sampled. The Teflon filters were also analyzed at Crocker Nuclear Laboratory by X-ray Fluorescence (XRF) and Particle-Induced X-ray Emission (PIXE) for elements Na-U, by

Proton Elastic Scattering Analysis (PESA) for hydrogen, and by Hybrid Integrating Plate and Sphere (HIPS) for light absorption (Eldred, 1988). The light absorption is related to the mass of soot carbon on the filter, while the hydrogen is related to the mass of organic carbon. We use these and the other elemental concentrations to calculate soot concentration, organic mass concentration, a composite soil concentration, and the total reconstructed mass (sum of species). These composite species and the gravimetric mass concentrations are shown in Appendix A for each test period.

Table 2. Sampling Site Configuration

Street	Location	Roadway Width (meters)
Sunrise Boulevard	North	39.4
Sunrise Boulevard	South	39.7
Greenback Lane	West	37.1
Greenback Lane	East	37.1
Sampler location	Distance North (m)	Distance East (m)
NE Corner	21.6	20.7
SW Far	-136.7	-54.4
SW Corner	-25.2	-31.5
SE Corner	-23.1	46.2
NE Corner	111.8	99.8

Road vacuuming

We collected the road surface material using a Hoover Porta-Power II canister vacuum, model number S1315, with removable bags (type R) using procedures outlined in AP-42, Appendix D (U.S. EPA, 1995). We vacuumed within the outlined crosswalks of the intersection. The two crosswalk areas vacuumed on Sunrise Boulevard were 86.11 m^2, while the Greenback Lane areas were 91.44m^2.

Meteorological data

We measured meteorological parameters continuously at the NE corner and SW far sites. These parameters included wind speed and temperature at 0.5m, 1m, 2m, 4m, and 7.5m, wind direction and solar radiation at 4m, and relative humidity at 2m. The SW far station, located in a large parking lot with minimal traffic, was our primary meteorological station due to the lack of influence from buildings, trees, and traffic. The data were recorded on Campbell Scientific CR-10 data loggers in 5-minute averages. These battery powered, automatic weather stations and their sensors meet all federal (EPA PSD standards) and state agency requirements.

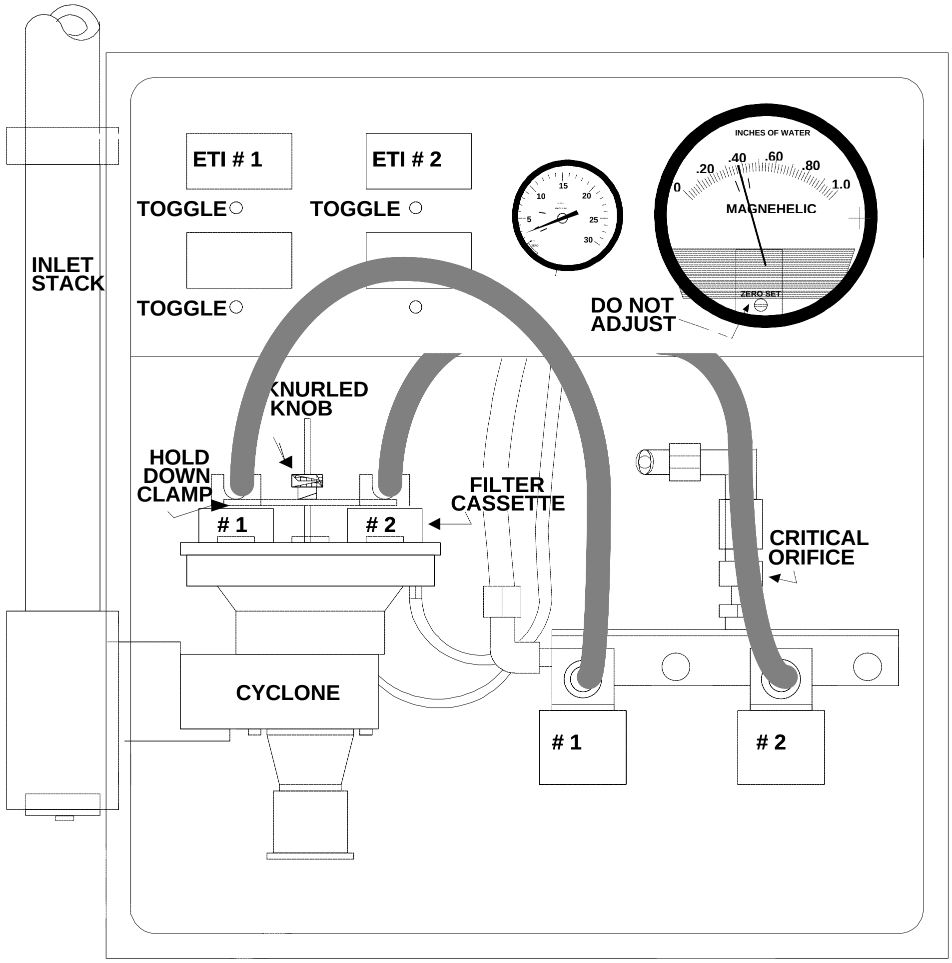

Figure 2. IMPROVE PM2.5 sampling module

Results

Traffic

Traffic counts were provided by the County of Sacramento from February 26th at 12:00 a.m. through March 4th 12:00 p.m. The counts were averaged and recorded hourly. Figure 3 shows the traffic volume at each of the approaches to the intersection, and the total traffic volume during the study period. Table 3 shows the traffic volume for the intersection and for each approach for each test period. Because the test periods did not start and stop on the hour, the traffic volumes for each test period in Table 2 were estimated from the hourly data. We assumed the hourly traffic volume was constant during each hourly count, and computed the fraction of the hour covered by the sampling period to arrive at the fractional hourly traffic volume for each test. The total traffic volume for each test period is the sum of the fractional hourly traffic volumes during the sample period. The Sunrise Boulevard southbound traffic counter failed from March 2nd at 10:30 a.m. until the end of the counting period. Consequently, total traffic counts in this time period were estimated by averaging the southbound traffic counts from previous weekdays.

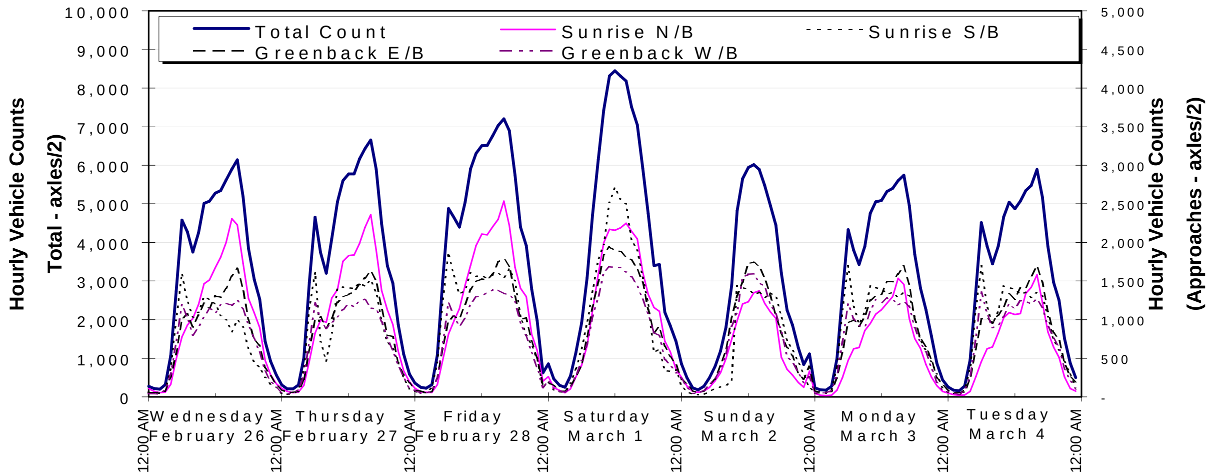

Figure 3. Traffic volume at the four approaches to Sunrise Boulevard and Greenback Lane during the sample period

Table 3. Average hourly vehicle counts for the intersection and each approach during each test period

TESTID	Intersection	Sunrise Northbound	Sunrise Southbound	Greenback Eastbound	Greenback Westbound
97-013	5570	1447	1331	1554	1238
97-014	4216	981	1241	1013	982
97-015	5371	1796	1111	1322	1143
97-016	5057	1745	844	1358	1110
97-017	3683	1080	668	982	952
97-018	5801	1833	1426	1368	1174
97-019	5679	1881	1281	1426	1090
97-020	5342	1342	1522	1321	1157
97-021	7899	2158	2342	1804	1594
97-022	3939	1185	860	1003	890
97-023	5054	1091	1396	1347	1220
97-024	4216	981	1241	1013	982
97-025	4991	1533	1183	1204	1071
97-026	5339	1909	875	1409	1146
97-027	4027	1158	852	1044	974
97-028	5679	1881	1281	1426	1090
97-029	2397	761	516	603	517
97-030	470	109	141	119	101
97-031	4743	1098	1536	1059	1050

Road surface silt loading

Table 4 shows the silt loading measurements at the crosswalk for each side of the Sunrise Boulevard/Greenback Lane intersection. The Sunrise Boulevard silt loadings were significantly higher than the Greenback Lane silt loadings. These measurements were also an order of magnitude higher than all but one of the measurements at Florin Road/Stockton Boulevard in August, 1995. Table 4 also shows the calculated PM_{10} and $PM_{2.5}$ emission rates using the predictive equation provided by the EPA in AP-42 (U.S. EPA, 1995). Note that the earlier study (UC Davis, 1996) found lower actual emission rates than those calculated using the EPA equation.

Table 4. Measured roadway silt loading and calculated PM_{10} emissions from paved roads using AP-42

	Sunrise Crosswalk		Greenback Crosswalk	
	North	South	West	East
Measured Roadway Silt Loading (mg/m^2)	33.2	26.1	18.4	13.6
Calculated PM_{10} Emission Rate (mg/VKT)	17.3	14.8	11.8	9.7
Calculated $PM_{2.5}$ Emission Rate (mg/VKT)	7.9	6.8	5.4	4.4

Meteorology

The meteorology varied from day to day throughout the test, as shown in Figure 4. The wind direction sometimes changed dramatically during the day, and other times was consistent for long periods The wind speed was often below 2 m/s, and provided good conditions for “hot spot” investigation during those times. On the last day of the test period, the wind speed dropped to nearly zero, and the direction fluctuated greatly, indicating an extended period of calm winds. This was the most ideal time period for a “hot spot” to develop. The meteorological conditions during each test period are summarized in Table 5.

The temperature and relative humidity at the NE Corner tower are shown in Figure 5. A pronounced diurnal pattern is evident, although there are some differences from day to day. The first test day was much drier than the others. The highest RH approached 90% at the end of the study, but it was not foggy during the tests.

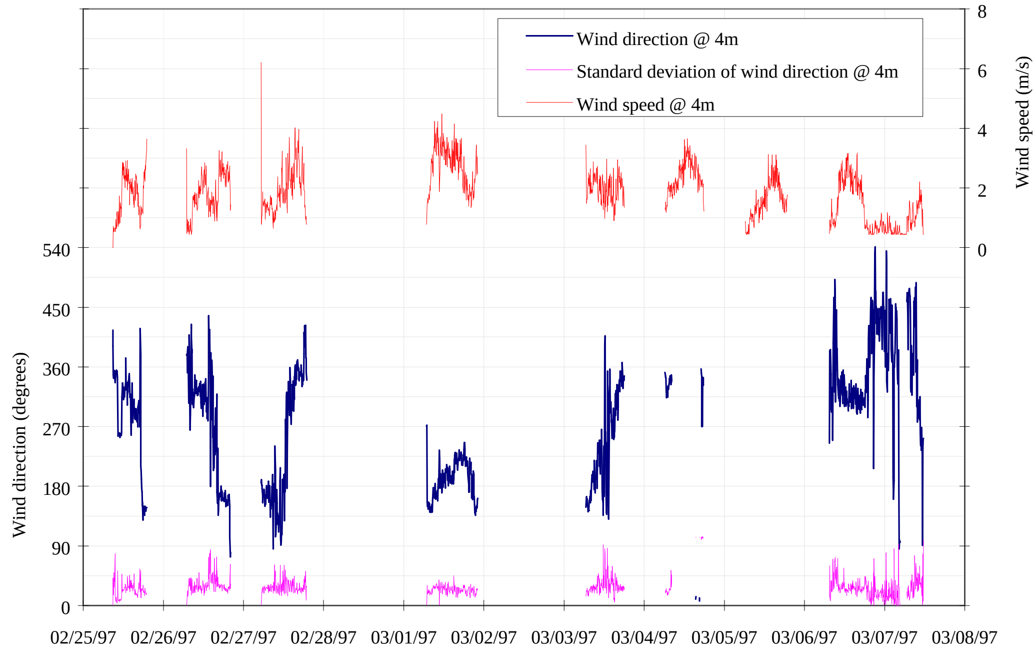

Figure 4. **Wind speed, wind direction, and standard deviation of wind direction during the study period**

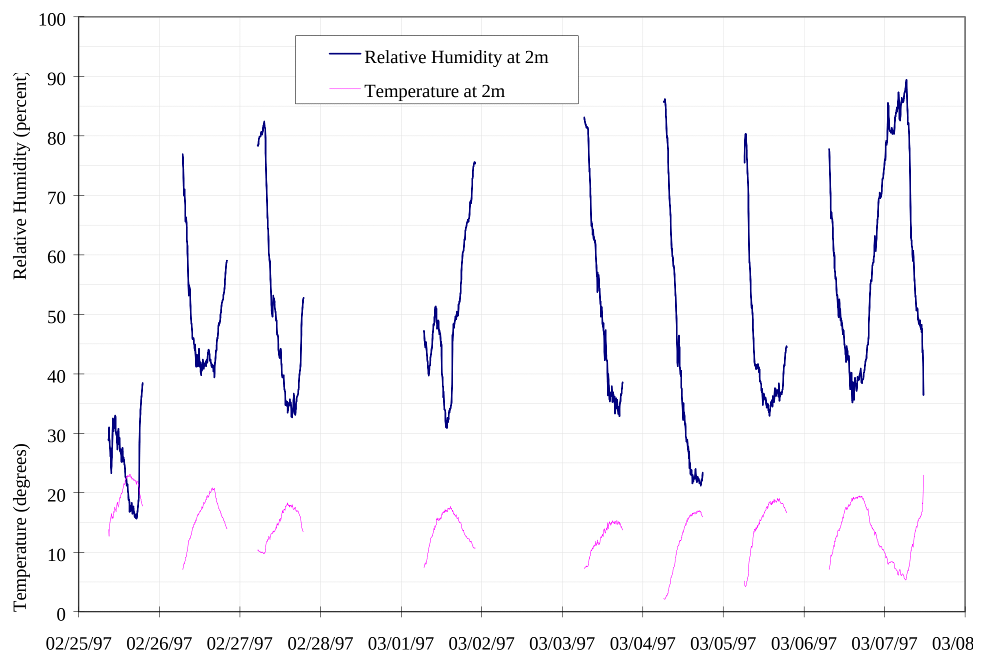

Figure 5. **Temperature and relative humidity at 2 meters height during the study period**

Table 5. Meteorological conditions during each test period

			South Tower			North Tower		
Test	Start date/time	End time	Mean wind speed at 4m	Mean wind direction ± standard deviation at 4m	Mean Richardson number	Mean wind speed at 4m	Mean wind direction ± standard deviation at 4m	Mean Richardson number
97-013	2/25/97 16:31	18:50	1.55	183.2 ± 63.8	-0.025	1.62	208.3 ± 89.7	-0.033
97-014	2/26/97 6:44	10:00	1.44	311.6 ± 11.6	-0.006	1.12	344.0 ± 38.3	-0.082
97-015	2/26/97 10:00	16:13	2.11	287.0 ± 47.4	-0.068	1.77	305.9 ± 51.1	-0.031
97-016	2/26/97 16:13	18:30	3.18	151.1 ± 10.0	-0.015	2.50	165.5 ± 16.7	-0.015
97-017	2/27/97 7:00	10:00	1.27	149.7 ± 29.1	-0.062	1.26	162.3 ± 29.9	-0.042
97-018	2/27/97 10:00	16:04	2.77	230.9 ± 88.3	-0.038	2.23	243.2 ± 90.0	-0.028
97-019	2/27/97 16:30	18:30	3.35	343.3 ± 22.1	-0.002	2.38	357.9 ± 26.1	-0.010
97-020	3/1/97 7:05	10:10	3.42	145.1 ± 9.8	-0.008	2.76	158.3 ± 11.8	-0.010
97-021	3/1/97 12:09	17:19	3.67	184.4 ± 16.2	-0.010	3.10	207.3 ± 15.8	-0.013
97-022	3/1/97 17:19	21:17	2.24	181.9 ± 18.9	-0.009	2.02	202.0 ± 25.0	-0.018
97-023	3/3/97 10:33	13:40	1.98	171.5 ± 47.6	-0.048	1.85	219.0 ± 81.2	-0.033
97-024	3/5/97 6:17	9:28	0.68	125.4 ± 14.4	0.078	0.84	N/A	-0.018
97-025	3/5/97 9:28	13:00	1.76	176.5 ± 35.4	-0.068	1.63	N/A	-0.044
97-026	3/5/97 14:00	18:30	2.44	161.6 ± 17.9	-0.019	2.05	N/A	-0.025
97-027	3/6/97 7:36	10:05	1.10	318.2 ± 74.0	-0.146	0.98	371.3 ± 62.4	-0.085
97-028	3/6/97 16:52	18:42	1.84	317.5 ± 9.1	0.040	1.30	319.3 ± 17.8	-0.038
97-029	3/6/97 18:42	23:16	0.59	N/A	0.137	0.62	59.3 ± 54.1	0.064
97-030	3/6/97 23:16	4:05	0.63	69.5 ± 57.1	0.073	0.62	60.2 ± 56.8	0.026
97-031	3/7/97 6:38	9:30	0.92	63.6 ± 56.5	-0.064	0.99	60.5 ± 53.7	-0.075

Particle concentrations

Figure 6 shows the PM_{10} concentration for each sample period averaged over all sampling locations. The organic carbon, soil, and soot concentrations are composites of the measured elemental concentrations. The reconstructed mass is the sum of these composites and several others, including all the measured elements. This figure shows the general trend of particle concentrations during the field study, with high concentrations developing in the evening of March 6 due to low wind speed and poor dispersion. Figure 4 clearly shows this episode as having the lowest wind speed of the study period. Table 5 also shows this period as having the most stable atmosphere, as the Richardson Number for both meteorological towers reached the highest positive value during this time period. Note that the PM_{10} mass concentrations shown in Figure 6 are the average of all measurements for each sampling period, including different heights, and do not represent individual measurements. These averages should not be compared to the PM_{10} NAAQS, as they are not 24-hour averages, but they can be used to discern particle concentration trends during the study.

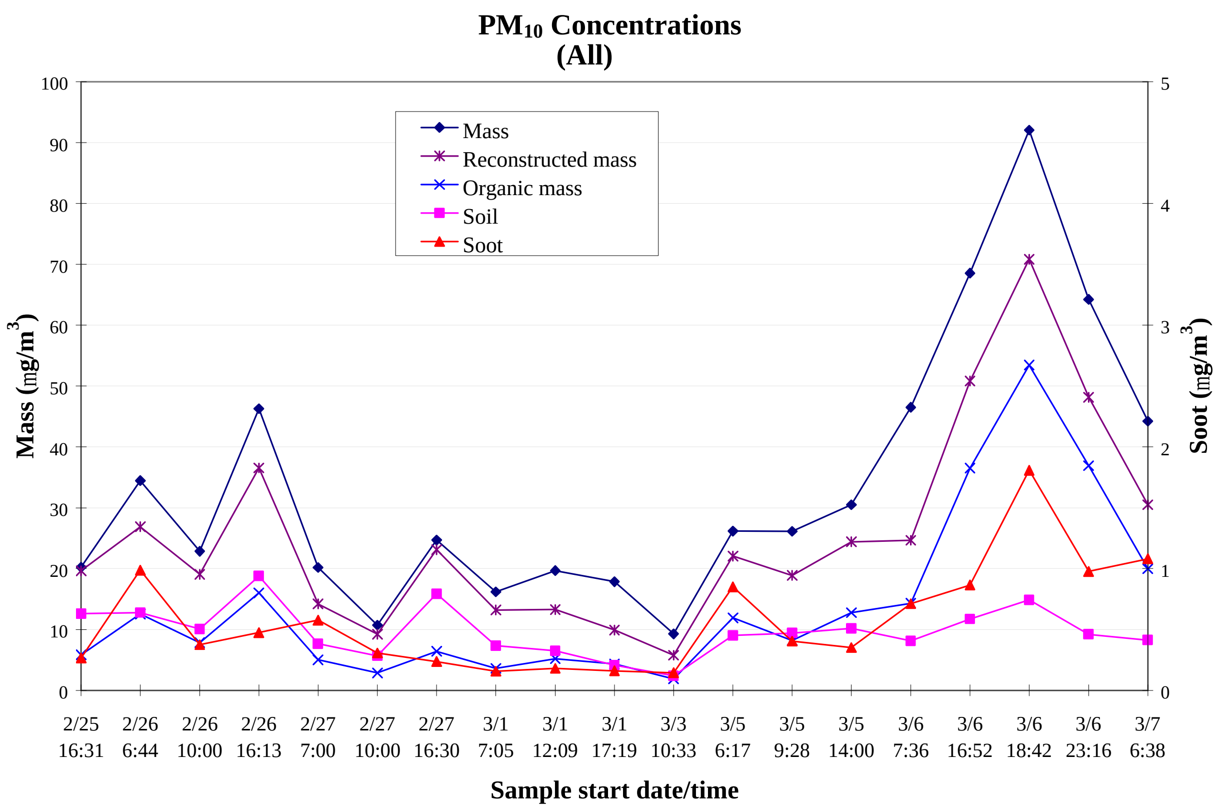

Figure 6. PM_{10} concentrations averaged for all sampling locations (soot concentrations are on the right-hand axis)

Particle composition

The composition of the particles changed during the study, as shown in Figure 7. During the final four sampling periods, when the stagnant winds and stable surface layer predominated, the soil fraction dropped to its lowest level and the organic mass (as measured by the hydrogen concentration) increased. The soot contribution to the total PM_{10} mass generally followed the organic mass, increasing toward the end of the study period, but also showed peaks in the morning hours on 2/26, 2/27, and 3/5. Soot is contributed primarily by diesel vehicles. At this site, soot is not a large fraction of the PM_{10} mass, but the correlation with organic mass suggests that organic mass is also contributed by vehicular traffic.

Overall, the measured species accounted for ~60-95% of the total PM_{10} mass, so during some sampling periods the composition was unknown for a significant fraction of the mass. This could have resulted from nitrate compounds or carbonaceous material that was not measured by the analytical methods employed in this study.

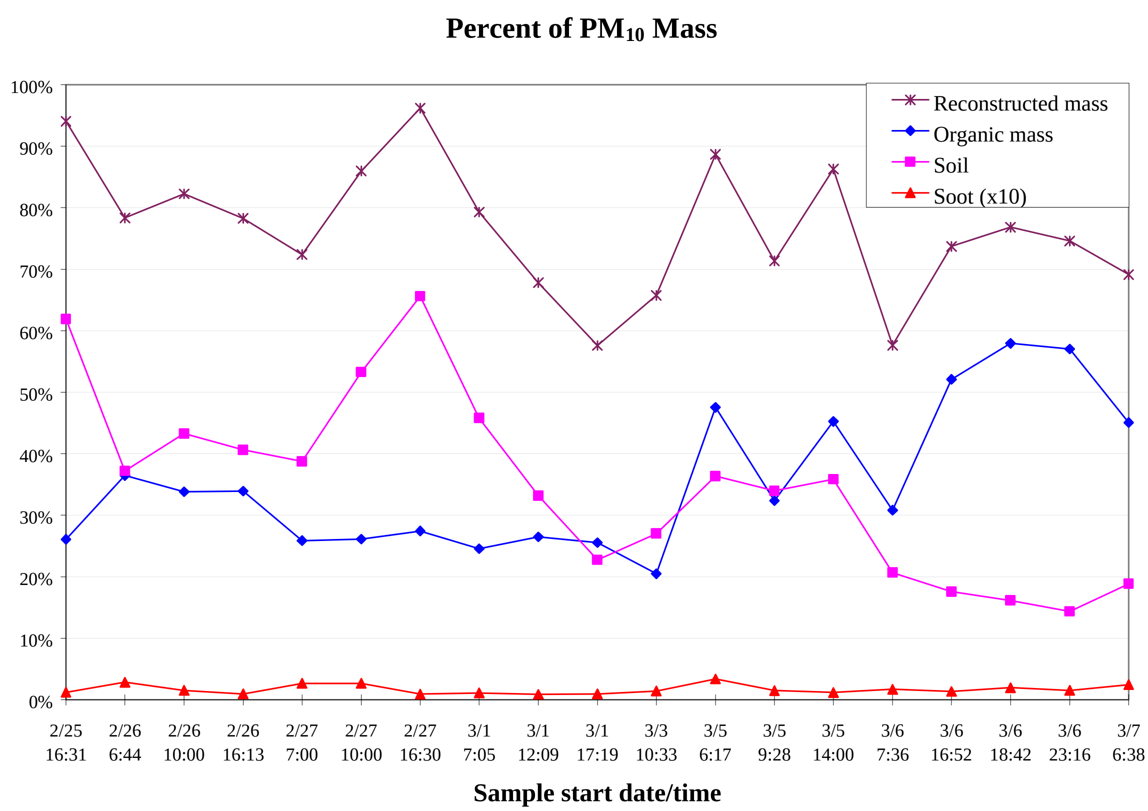

Figure 7. Ratio of particle composition to total PM10 mass for all sampling locations

Discussion

The primary objective of this study was to investigate whether a large intersection was likely to be a PM_{10} "hot spot" during periods of low wind speed and poor dispersion. The highest concentrations measured during this study occurred during such a period on March 6 from 6:45 p.m. to 11:15 p.m. The PM_{10} mass and composition for this time period are shown in Table 6 and are plotted in Figure 8. Similar plots for other time periods are shown in Appendix A.

The six vertical profiles of Figure 8 indicate that the intersection is unlikely to be a "hot spot" of PM_{10} even under stable, low dispersion meteorological conditions. The wind direction during this period was from the NE, and the wind speed averaged less than 1 m/s. The Richardson number was positive, indicating a very stable atmosphere. Even though the wind direction placed the NE Corner upwind, it fluctuated widely. Furthermore, the sampler was located only a few meters from the intersection corner and was close enough that the traffic wake could carry traffic-generated particles to the sampler. By all measures except soot, the two corner sites had nearly identical concentrations above 3m height, although the 1m measurement was higher at the SE Corner than at the NE Corner. The concentrations at the SW Far site were higher than at the intersection in nearly all cases, which suggests that the intersection was not acting as a "hot spot" of PM_{10}. The SE Corner had higher soot concentrations than the NE Corner at all heights, but the SW Far site had even higher soot concentrations at 3m. The highest measured concentrations did not approach the PM_{10} standard, and were sustained for only a few hours. Thus, the 24-hour average was even lower than the peak concentrations shown in Figure 8.

Table 6. PM_{10} mass and composition ($\mu g/m^3$) on March 6, 1997 from 6:45-11:15 p.m.

	NE Corner			SW Far			SE Corner		
Data	1 m	3 m	9 m	1 m	3 m	9 m	1 m	3 m	9 m
Mass	75.8	82.3	84.9	101.1	112.2	95.2	98.1	85.6	93.1
Reconstructed mass	56.0	66.1	64.8	79.3	84.7	74.8	85.4	65.1	61.0
Soot	1.6	1.6	1.6	1.6	2.4	1.8	2.0	1.8	1.9
Soil	13.8	13.0	14.1	15.6	19.3	15.9	13.8	13.1	15.2
Organic mass	39.9	50.9	48.5	61.2	62.2	56.4	69.3	49.4	43.2
Sulfate	1.6	1.5	1.5	1.8	2.0	1.6	1.3	1.6	1.6

Conclusions and Recommendations

The Sunrise Boulevard/Greenback Lane intersection is not a "hot spot" of PM_{10} emissions under the meteorological and traffic conditions measured. This finding confirms the earlier work at Stockton Boulevard/Florin Road, a much smaller intersection. The highest concentrations measured during this study occurred during stagnant conditions, as expected, but they did not approach the ambient air quality standard and were not centered on the intersection. Vehicle sources comprised a large fraction of the PM_{10} during the stagnant period at the end of the study.

If Caltrans desires to continue searching for PM_{10} "hot spots," it would be productive to make additional measurements using innovative technology such as lidar and real-time measurement methods along with the filtration samplers we have used to date. It would probably not be productive to continue making measurements with only the filter-based methods used in this and earlier studies. Lidar and real-time monitors would provide flexibility to make measurement decisions in the field and to observe changing conditions while there is time to react to them.

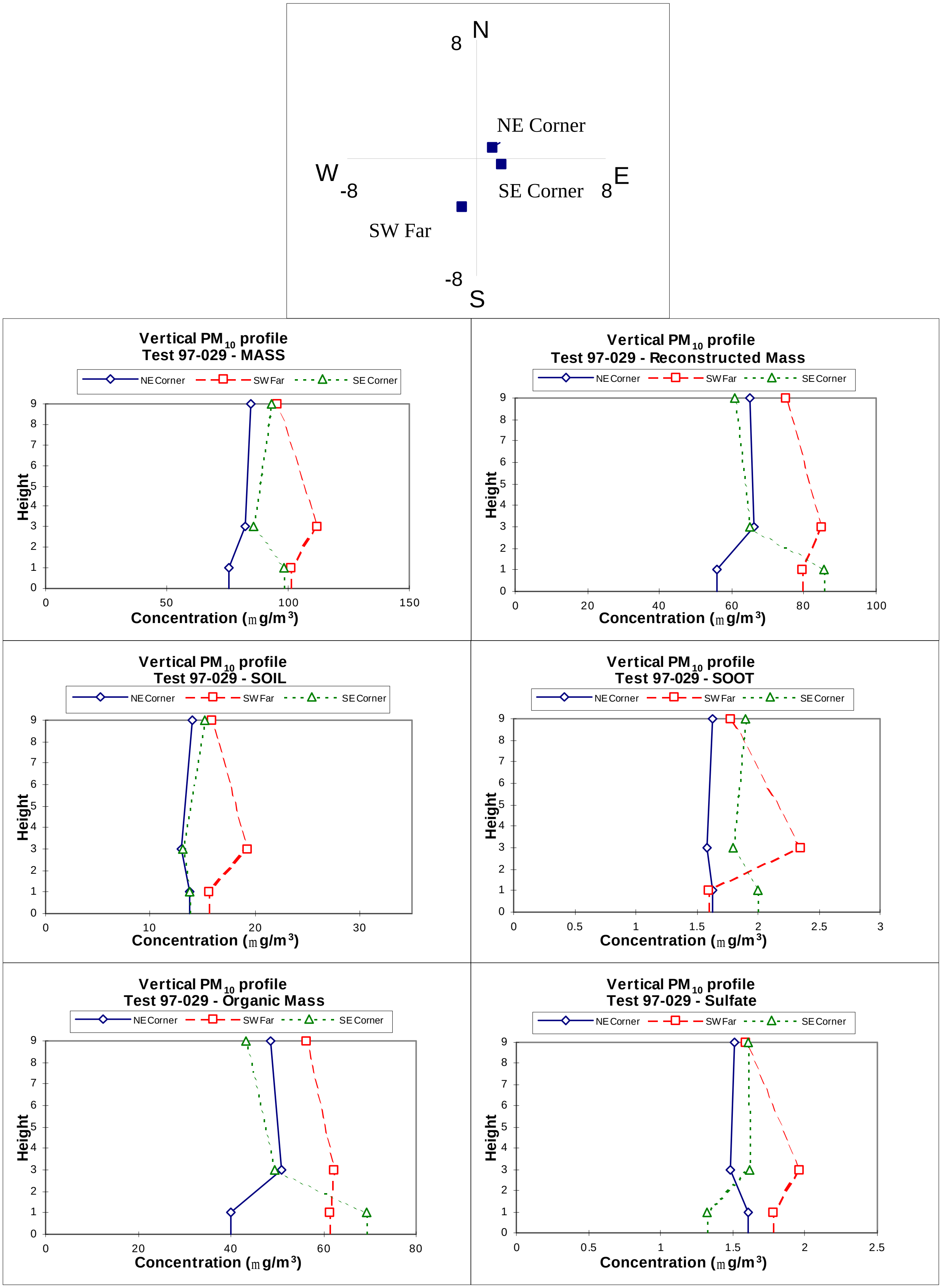

Figure 8. Vertical profiles of PM_{10} mass and composition, March 6, 1997 6:45-11:15 p.m.

Acknowledgments

A number of individuals outside the Air Quality Group assisted with this project. Doug Maas and Sonya Hernandez of Sacramento County Traffic Division provided traffic counts for all four approaches to the intersection. The managers of US Bank, Glendale Savings, and Michael Joe's European Salon allowed us to use several parking spaces during the study. The manager of Sunrise Mall also permitted use of their property, although we did not need to use it. The managers of Montgomery Ward were extremely helpful, allowing us use of their property, facilities, and electrical power. Security fencing was rented from Security Contractor Fences, and security guards were from Comprehensive Security Systems. Dan Chang of the UC Davis Department of Civil and Environmental Engineering contributed through discussions of the project and in coordinating the companion project operated by the Department of Civil and Environmental Engineering. Dan was also instrumental in obtaining permission to use the property at Sunrise Festival Mall.

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Appendix A: Vertical profiles of mass and composition for all test periods

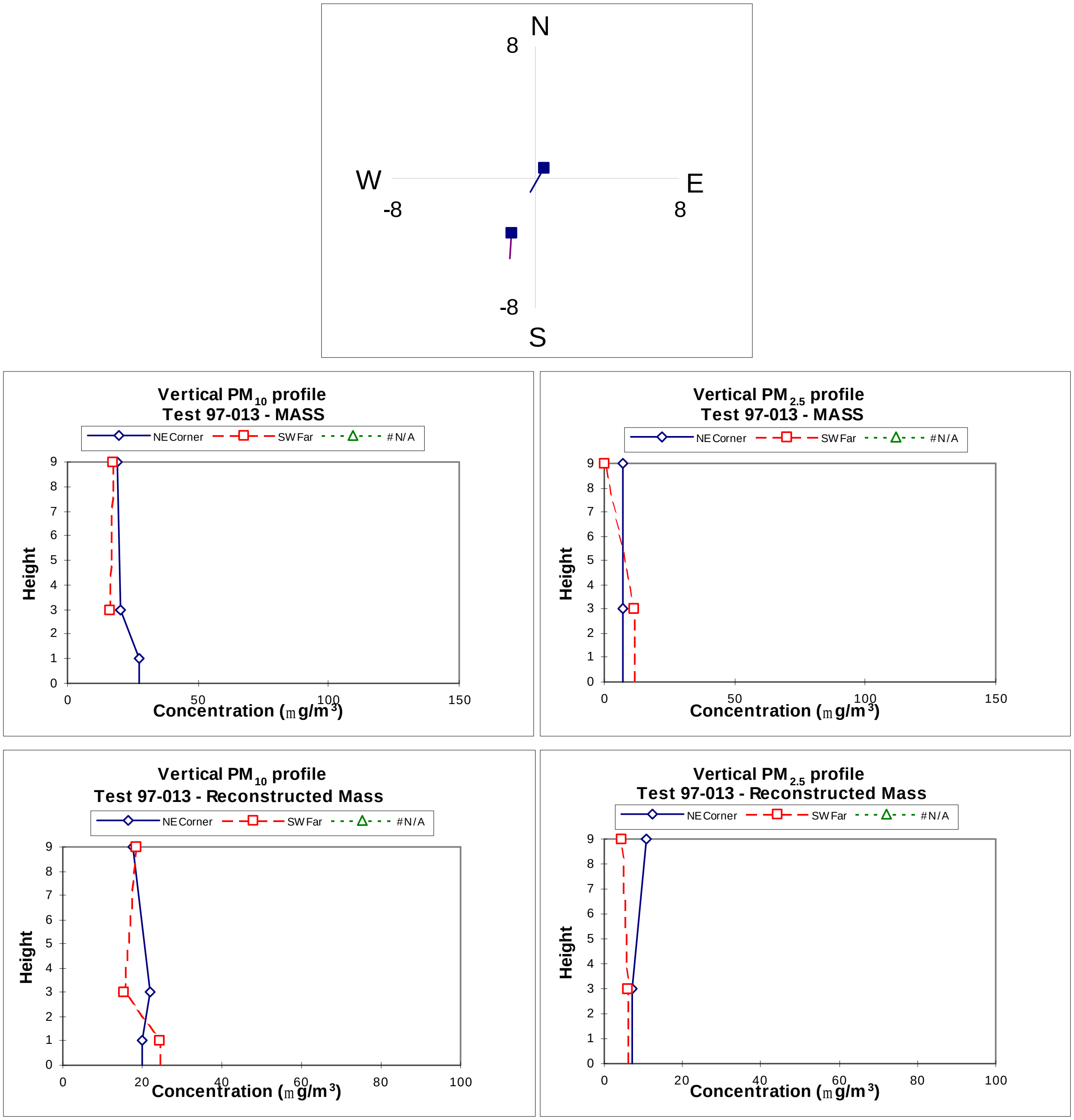


Figure 9. Wind vector plot and vertical profiles of mass and reconstructed mass, February 25, 1997 4:35 - 6:45 p.m.

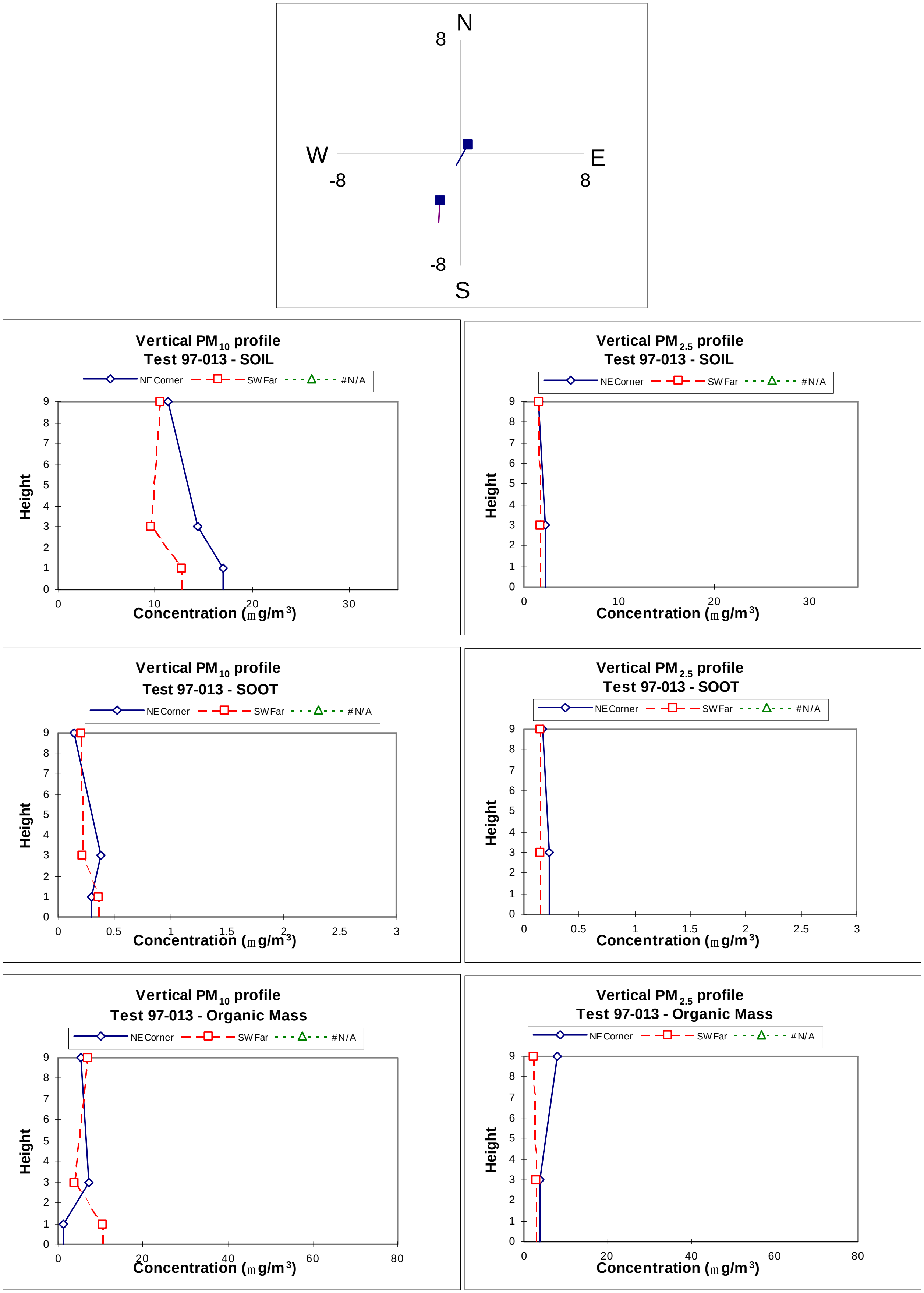


Figure 10. Vertical profiles of soil, soot, and organic mass, February 25, 1997 4:35 - 6:45 p.m.

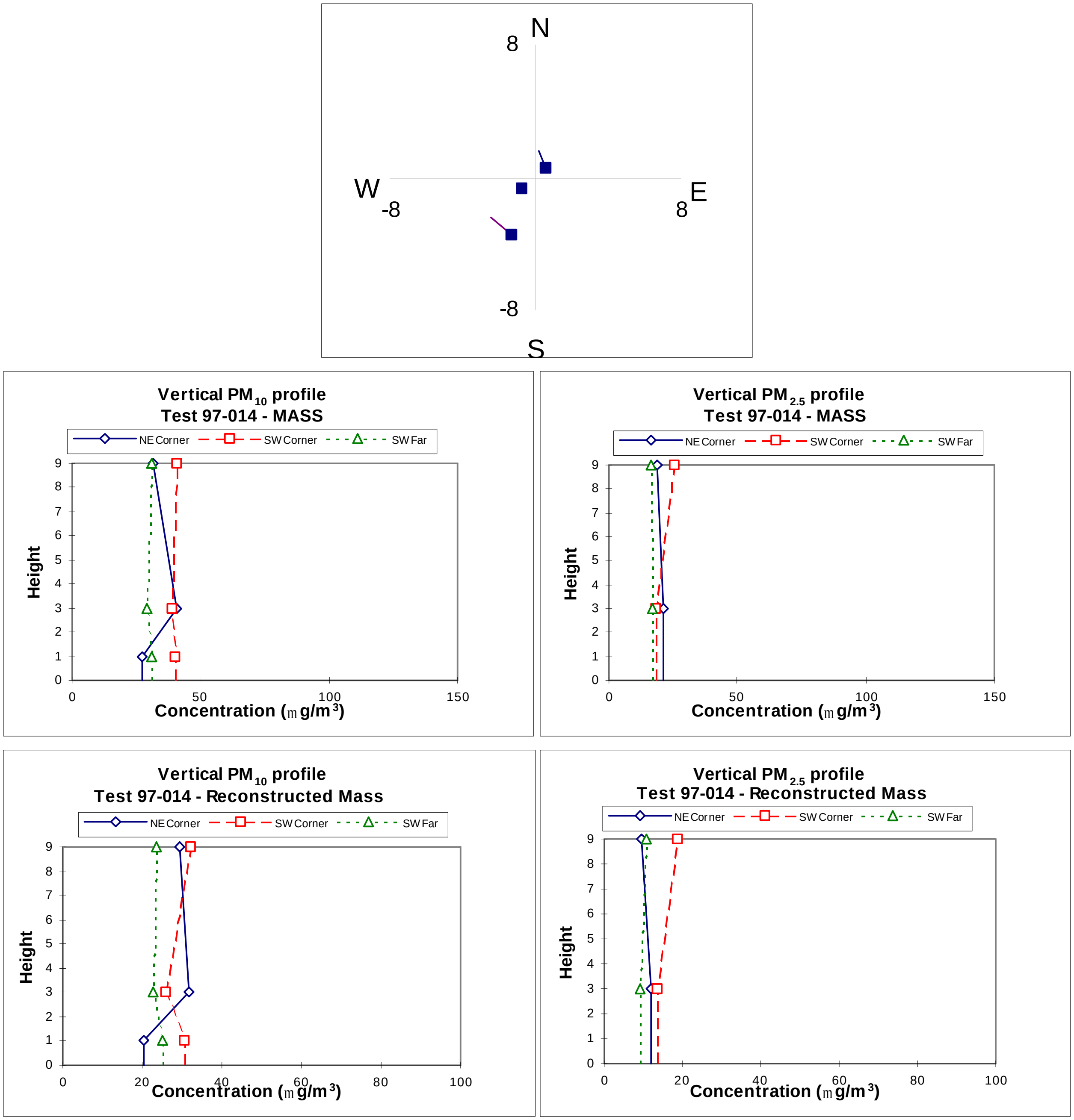


Figure 11. Wind vector plot and vertical profiles of mass and reconstructed mass, February 26, 1997 6:45 - 9:55 a.m.

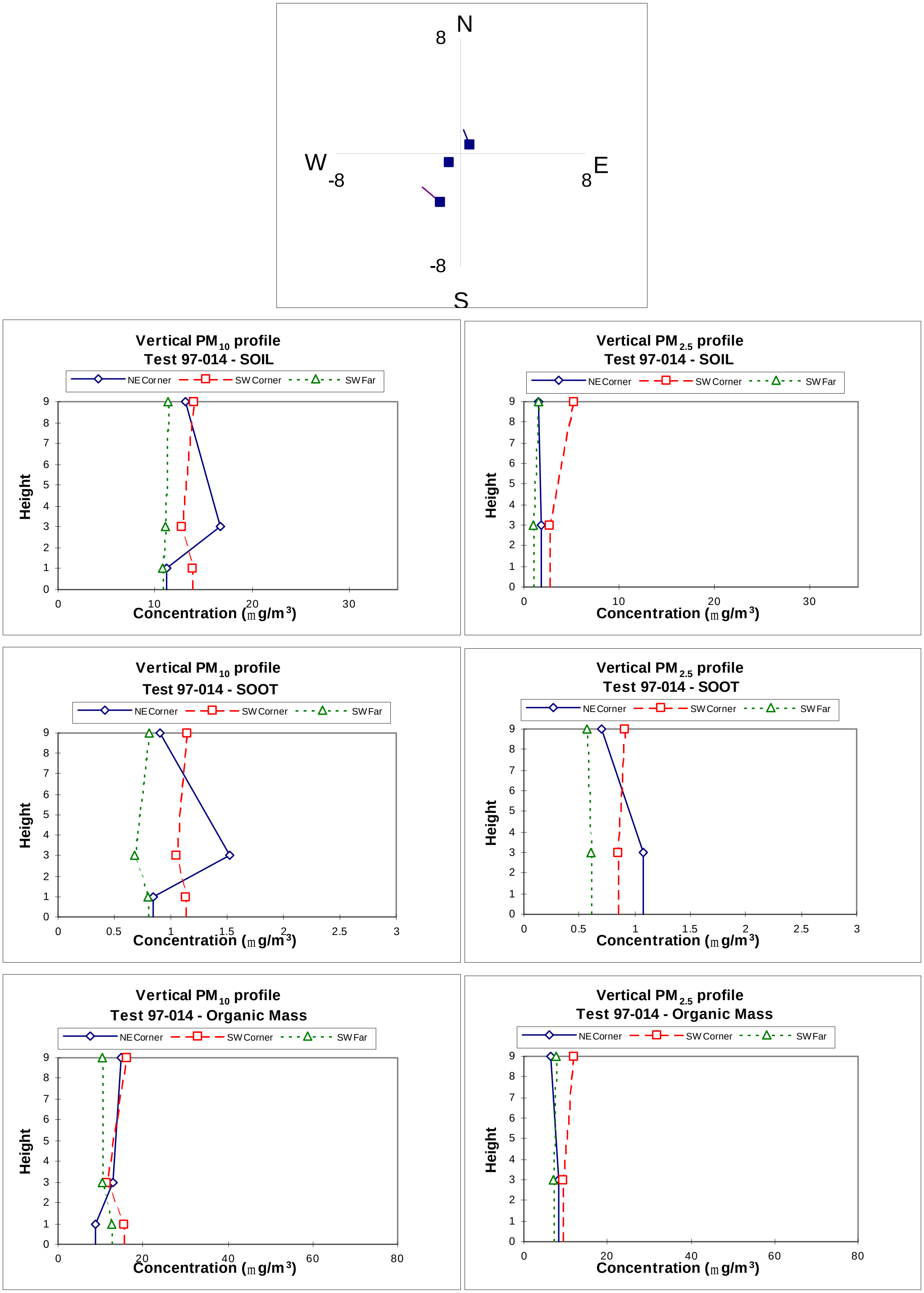


Figure 12. Vertical profiles of soil, soot, and organic mass, February 26, 1997 6:45 - 9:55 a.m.

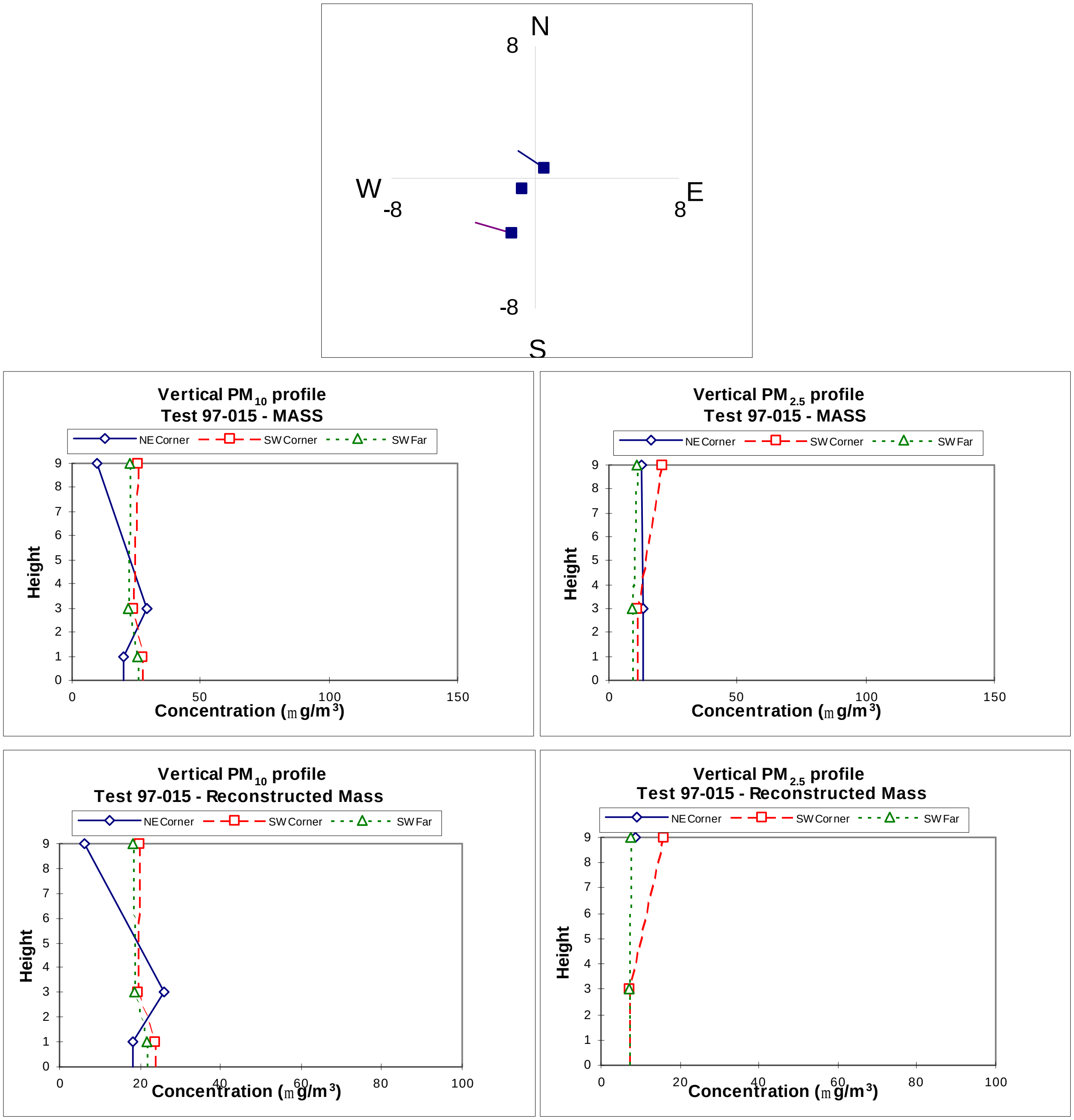


Figure 13. Wind vector plot and vertical profiles of mass and reconstructed mass, February 26, 1997 10:00 a.m. - 4:10 p.m.

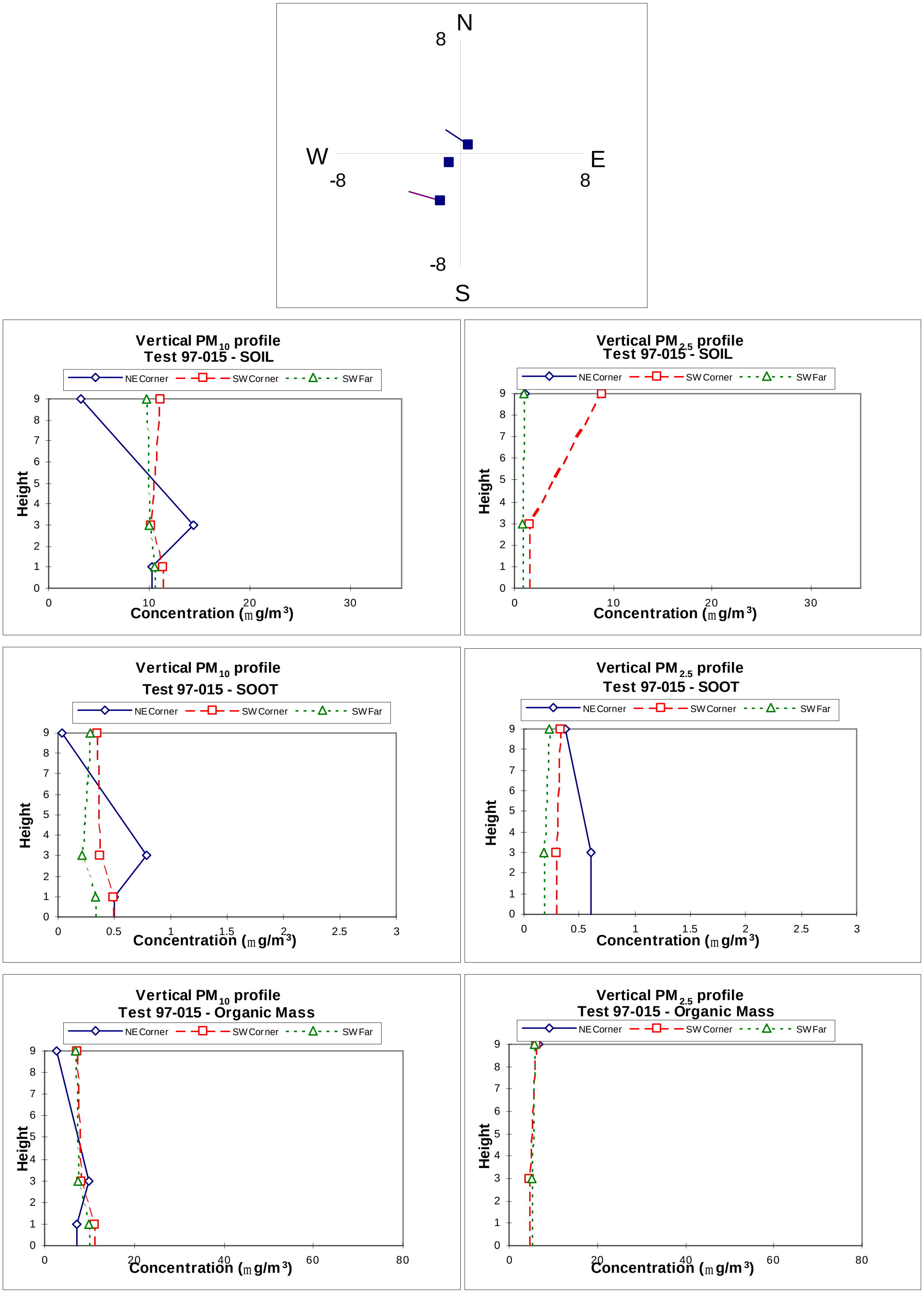


Figure 14. Vertical profiles of soil, soot, and organic mass, February 26, 1997 10:00 a.m. - 4:10 p.m.

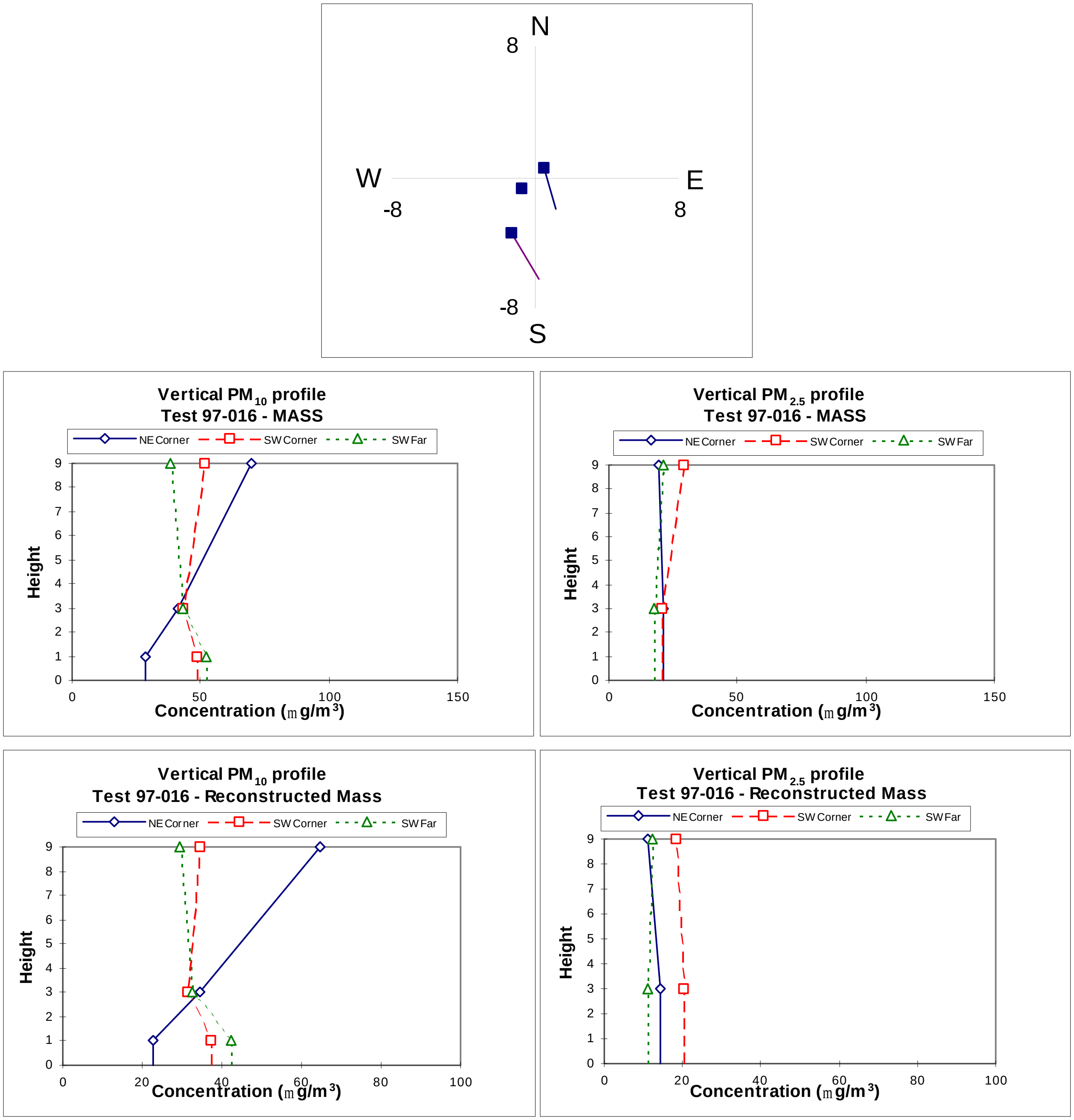


Figure 15. Wind vector plot and vertical profiles of mass and reconstructed mass, February 26, 1997 4:15 - 6:25 p.m.

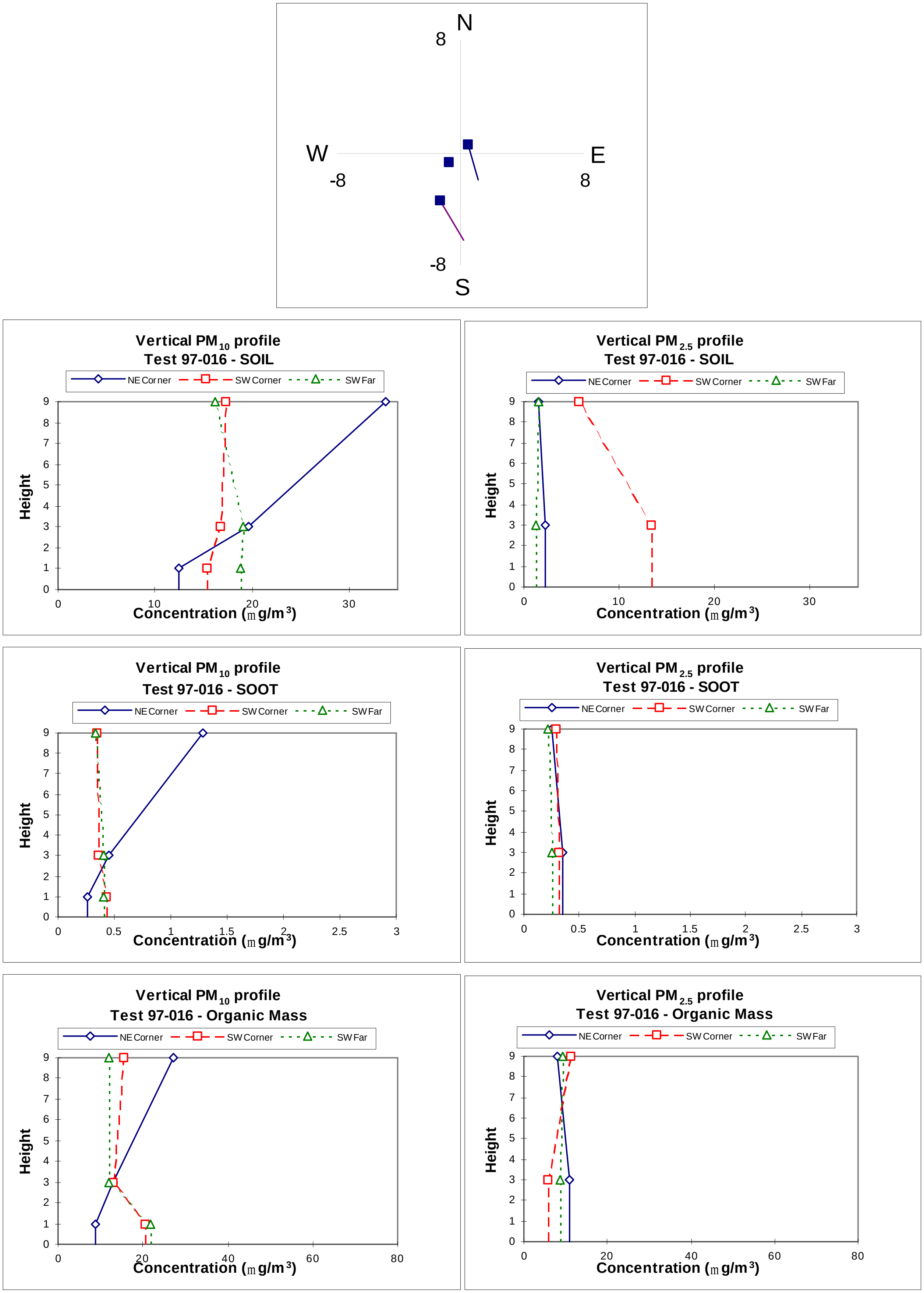


Figure 16. Vertical profiles of soil, soot, and organic mass, February 26, 1997 4:15 - 6:25 p.m.

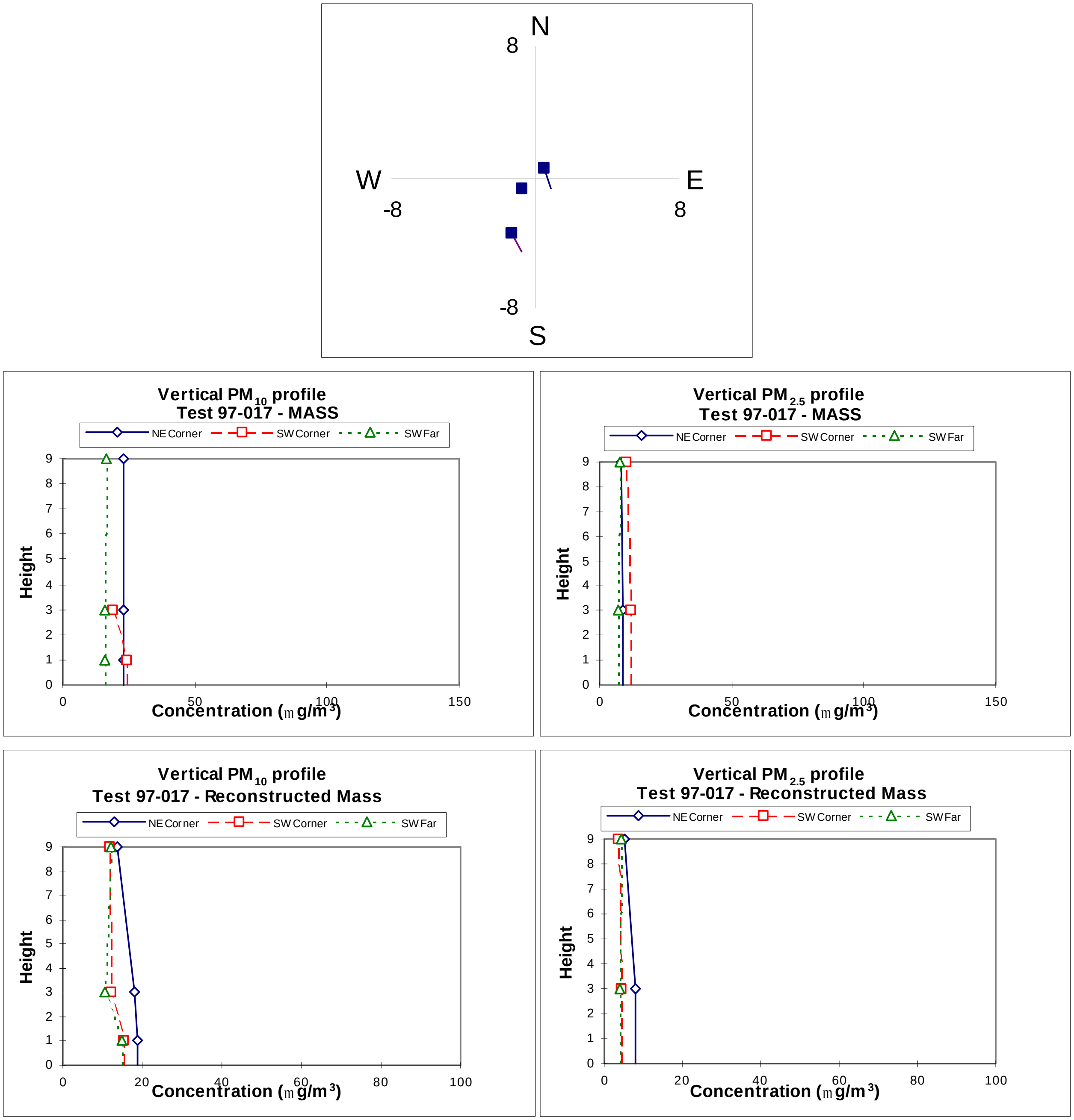


Figure 17. Wind vector plot and vertical profiles of mass and reconstructed mass, February 27, 1997 7:00 - 9:55 a.m.

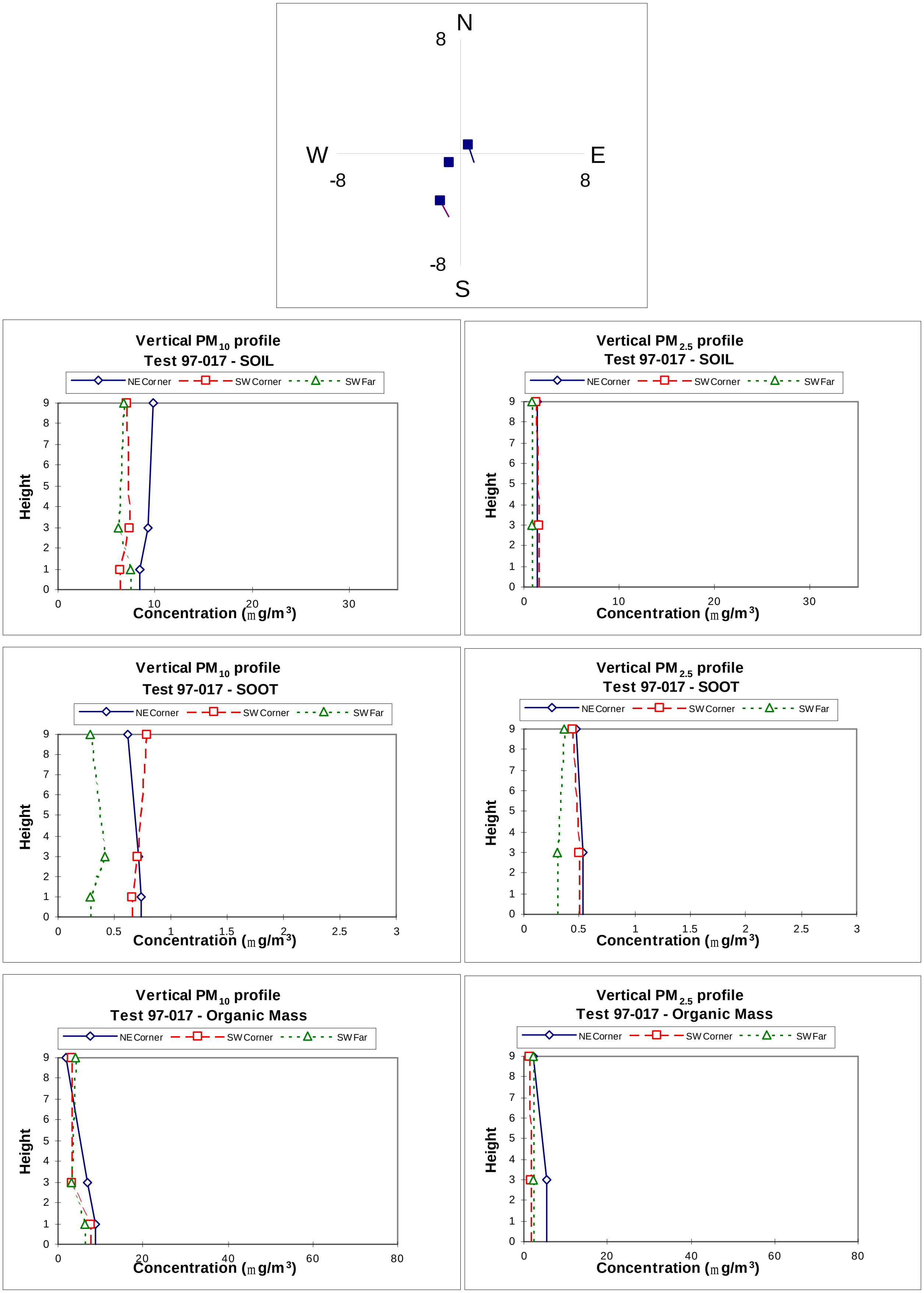
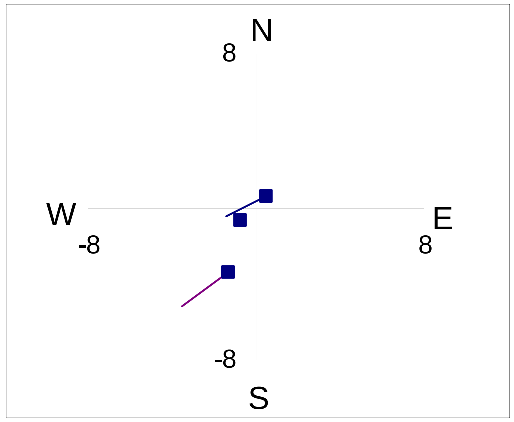
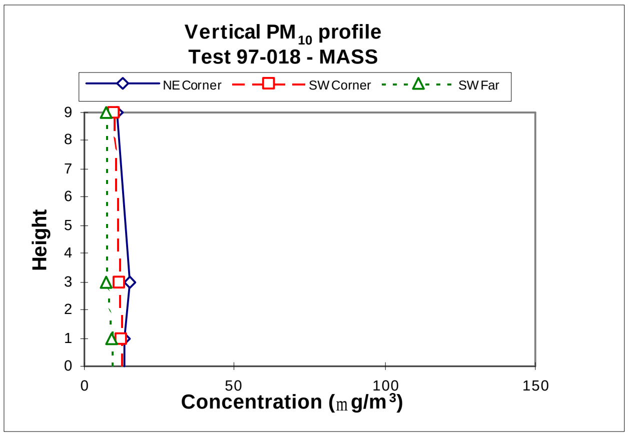
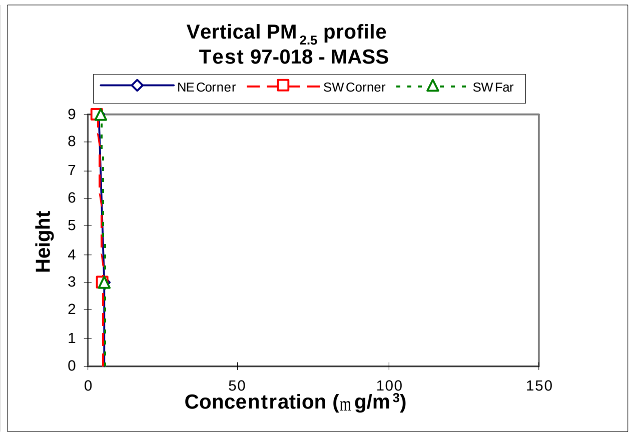
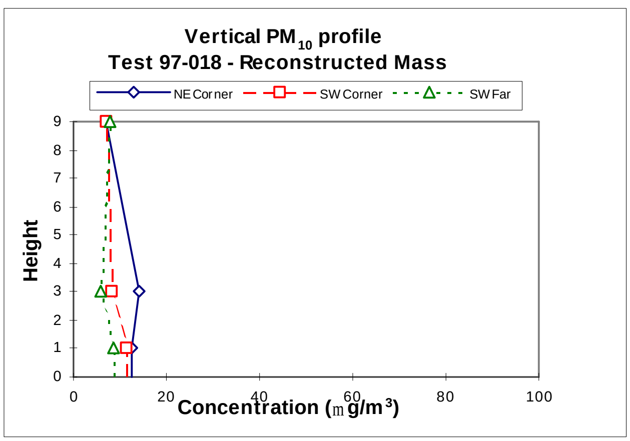


Figure 18. Vertical profiles of soil, soot, and organic mass, February 27, 1997 7:00 - 9:55 a.m.









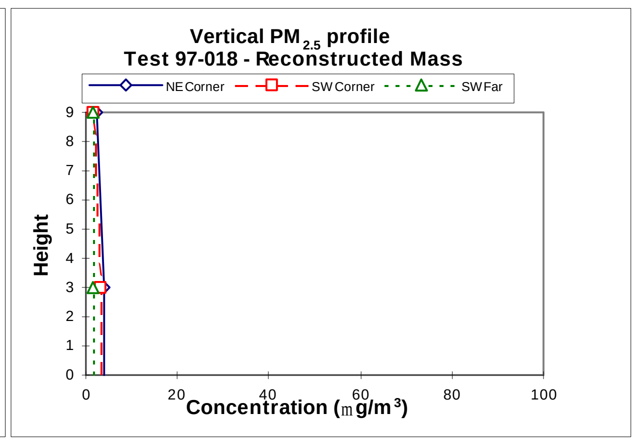


Figure 19. Wind vector plot and vertical profiles of mass and reconstructed mass, February 27, 1997 10:00 a.m. - 4:00 p.m.

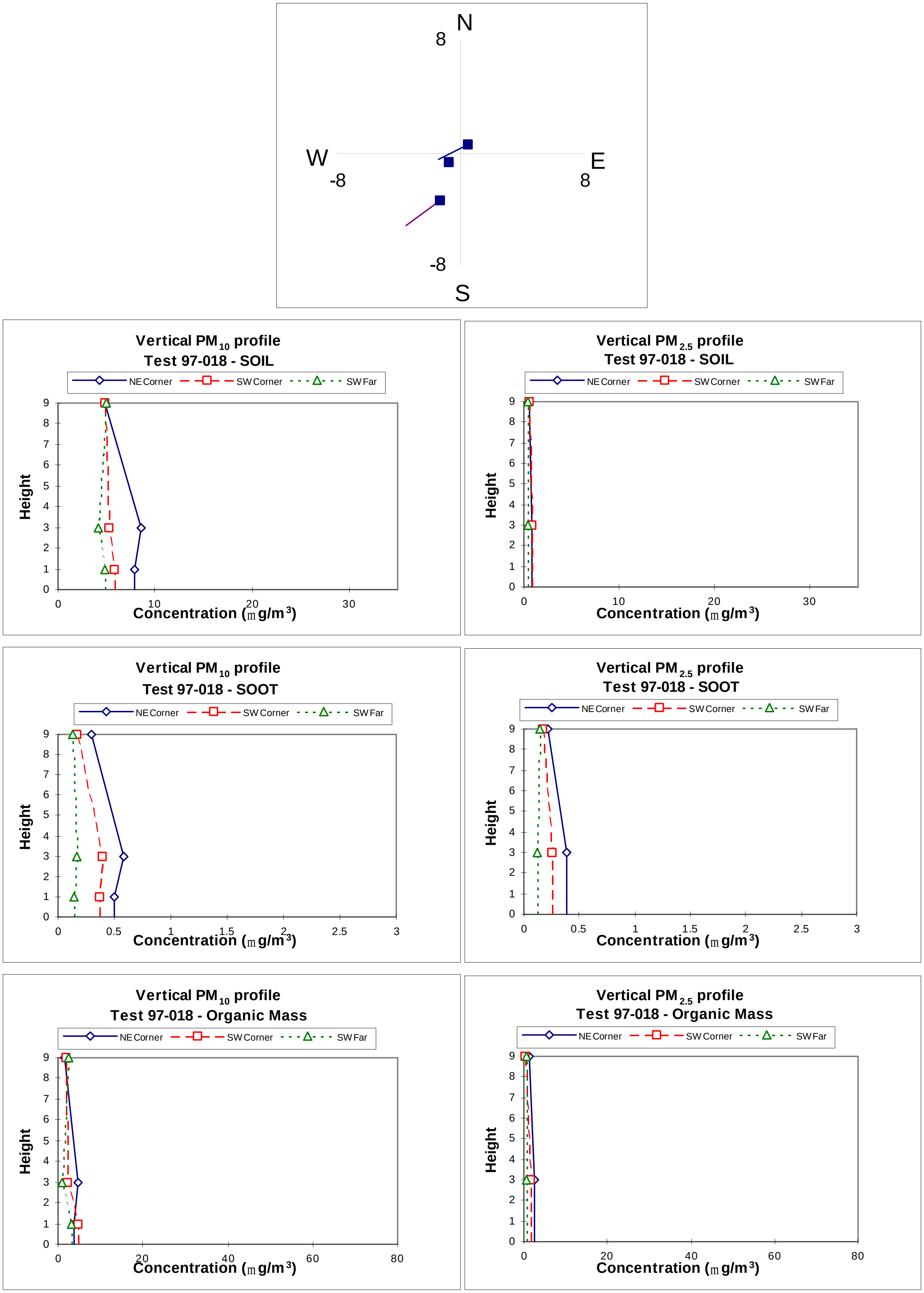


Figure 20. Vertical profiles of soil, soot, and organic mass, February 27, 1997 10:00 a.m. - 4:00 p.m.

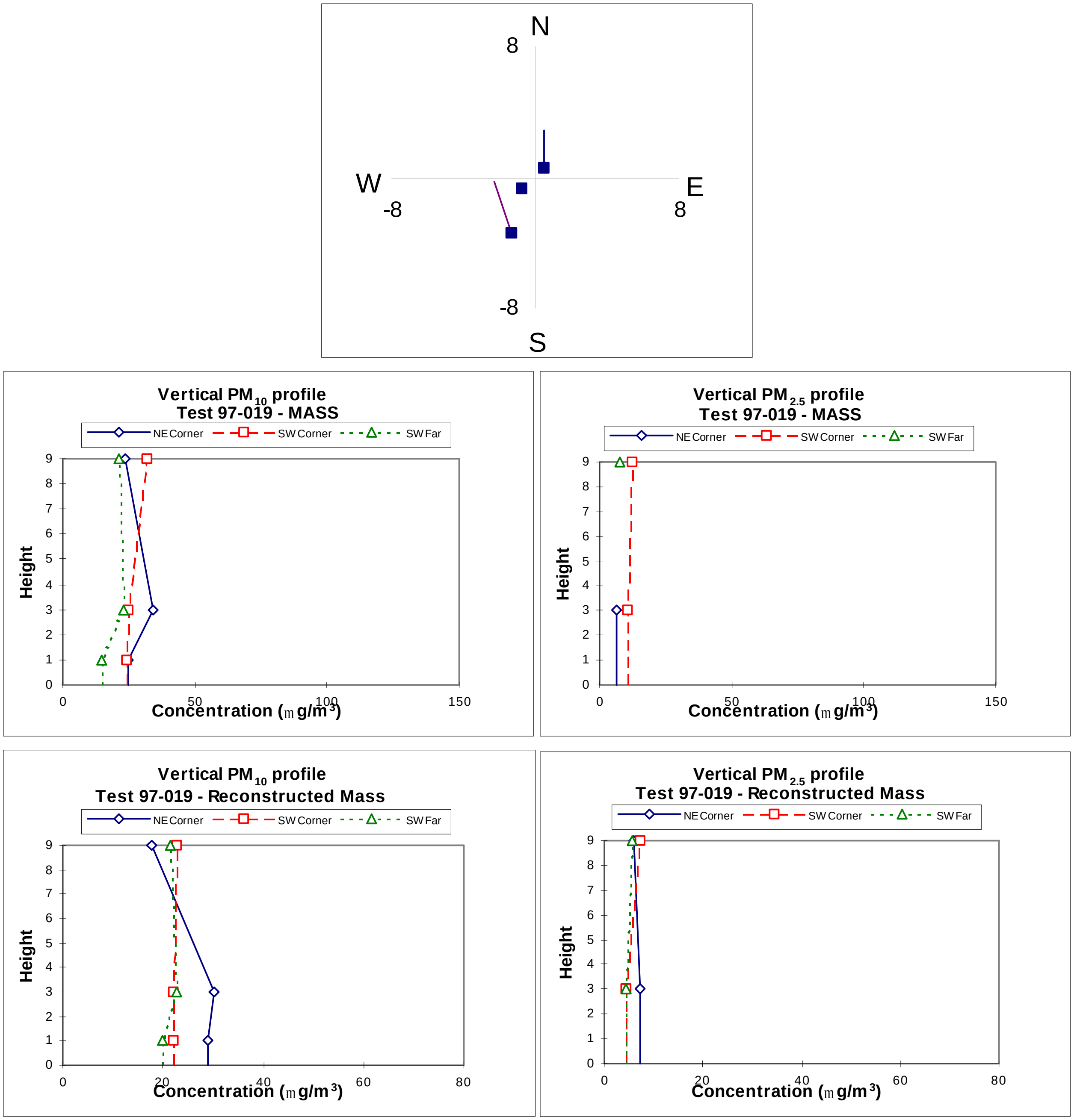


Figure 21. Wind vector plot and vertical profiles of mass and reconstructed mass, February 27, 1997 4:30 - 6:25 p.m.

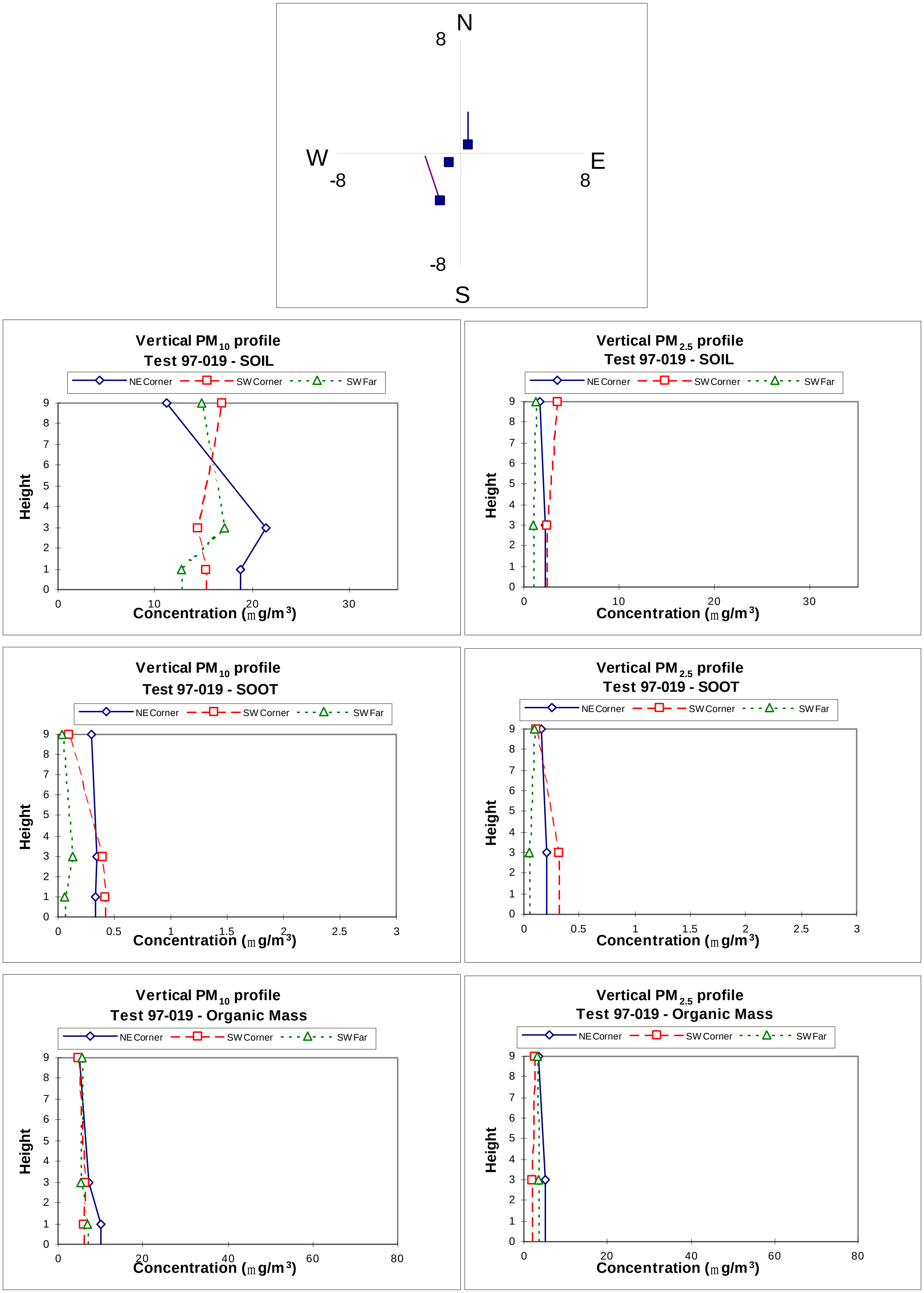


Figure 22. Vertical profiles of soil, soot, and organic mass, February 27, 1997 4:30 - 6:25 p.m.

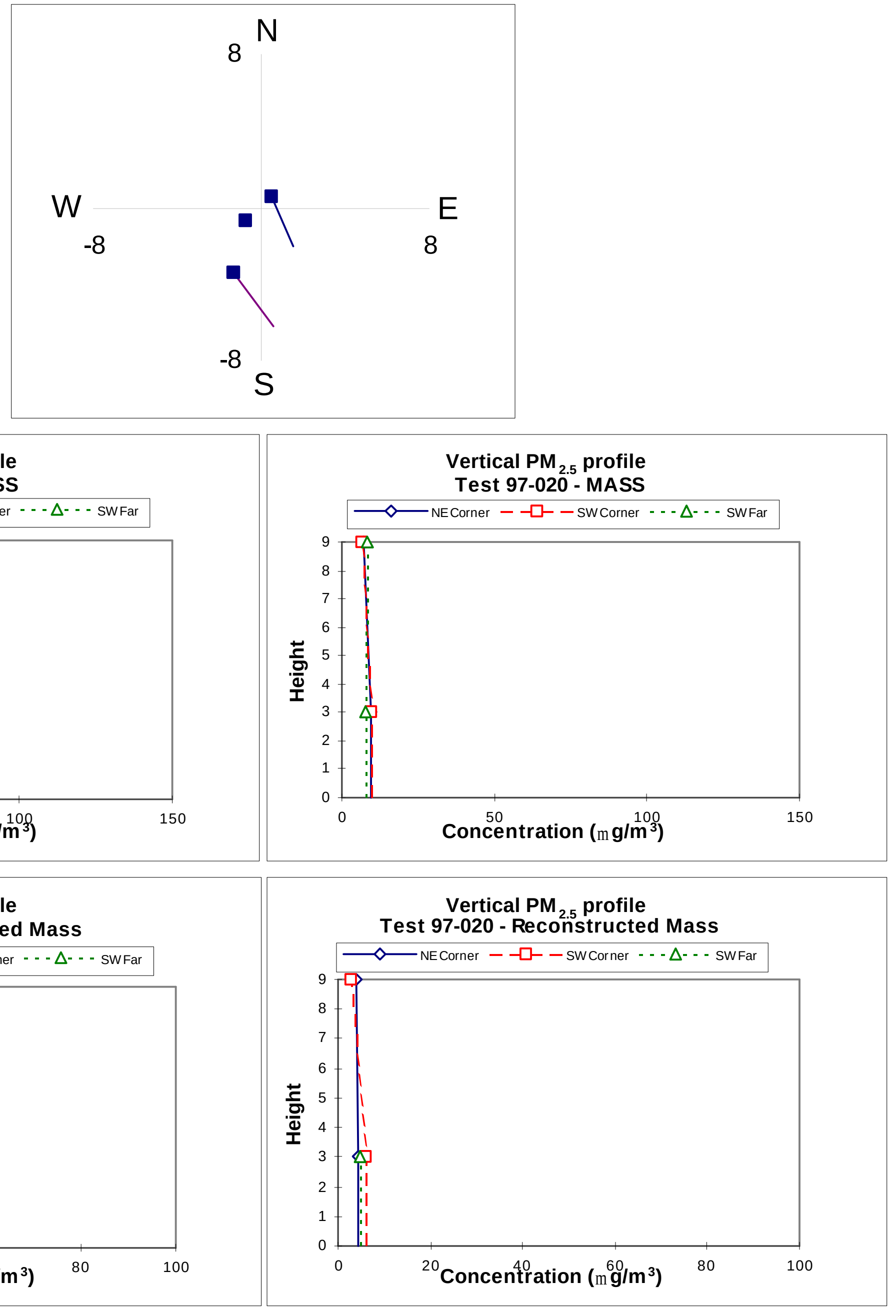


Figure 23. Wind vector plot and vertical profiles of mass and reconstructed mass, March 1, 1997 7:05 - 10:05 a.m.

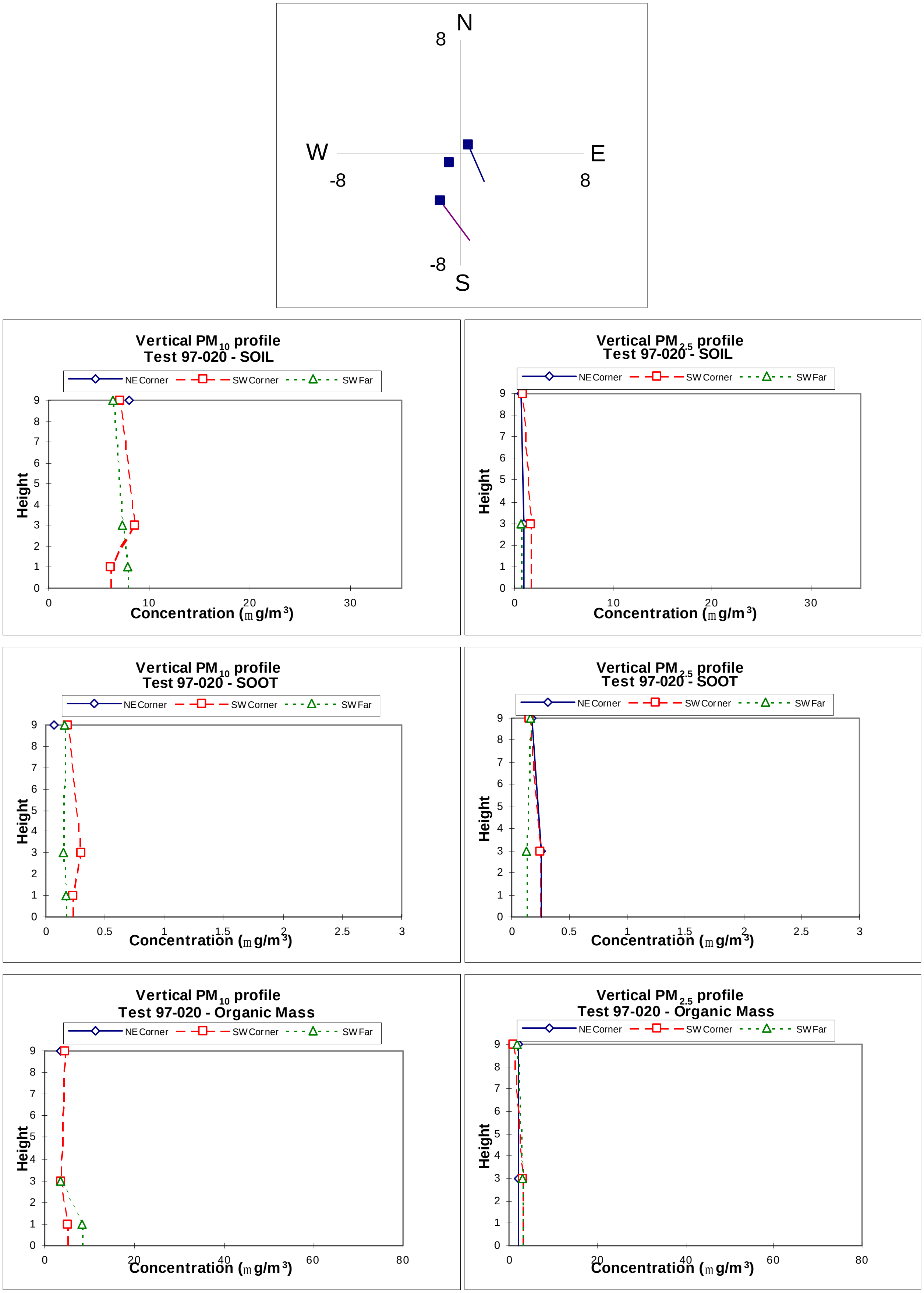


Figure 24. Vertical profiles of soil, soot, and organic mass, March 1, 1997 7:05 - 10:05 a.m.

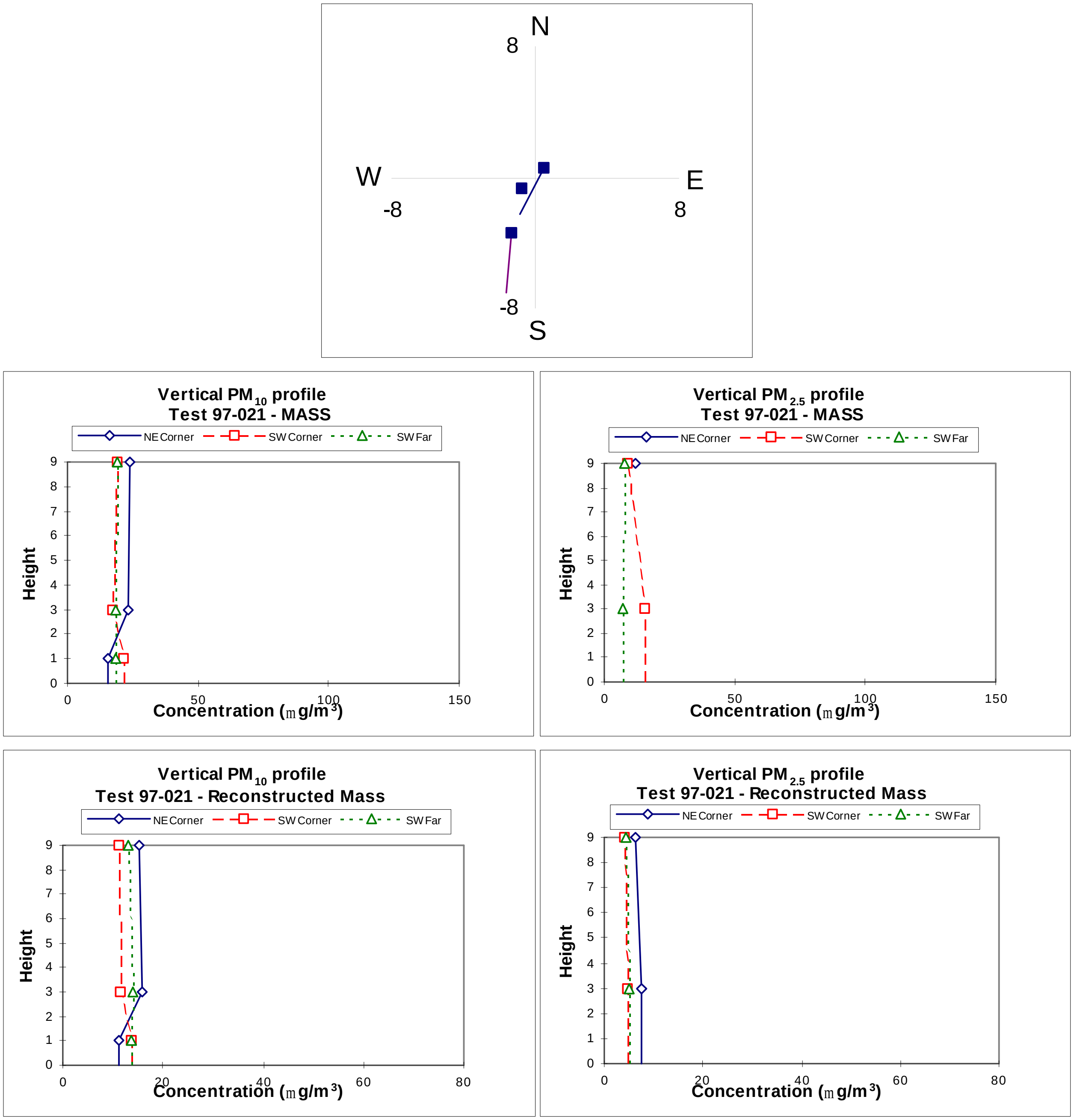


Figure 25. Wind vector plot and vertical profiles of mass and reconstructed mass, March 1, 1997 12:10 - 5:15 p.m.

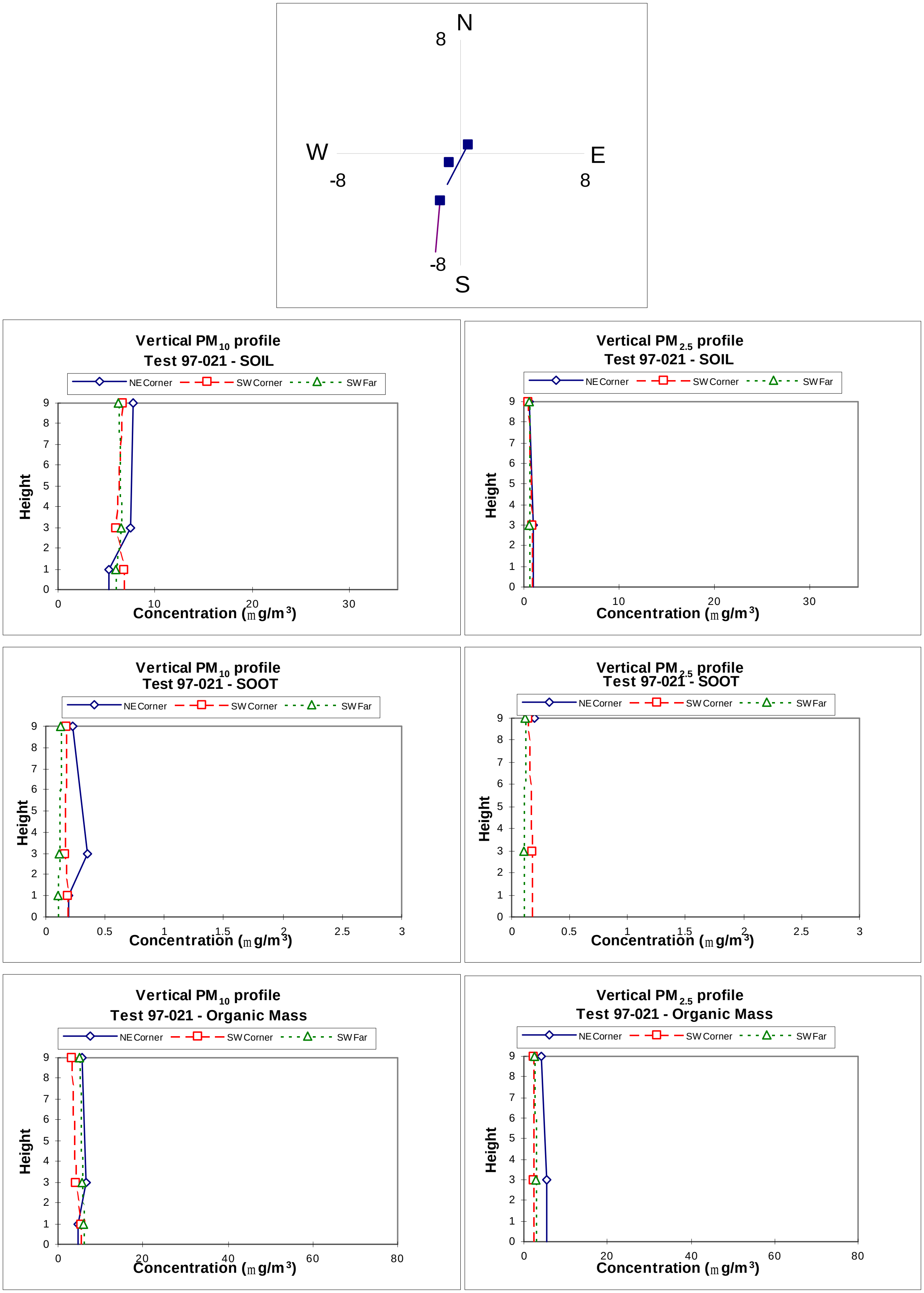


Figure 26. Vertical profiles of soil, soot, and organic mass, March 1, 1997 12:10 - 5:15 p.m.

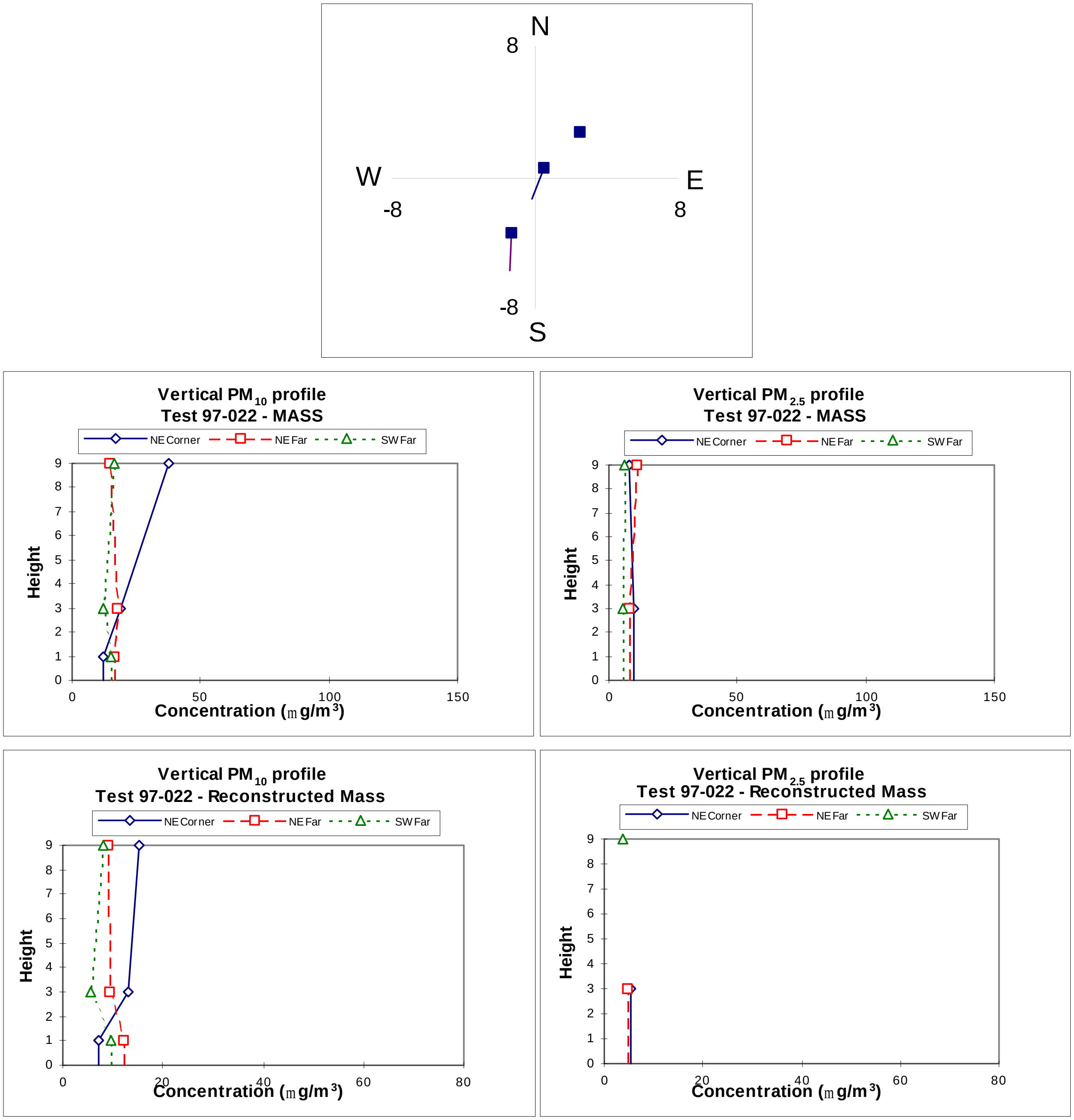


Figure 27. Wind vector plot and vertical profiles of mass and reconstructed mass, March 1, 1997 5:20 - 9:15 p.m.

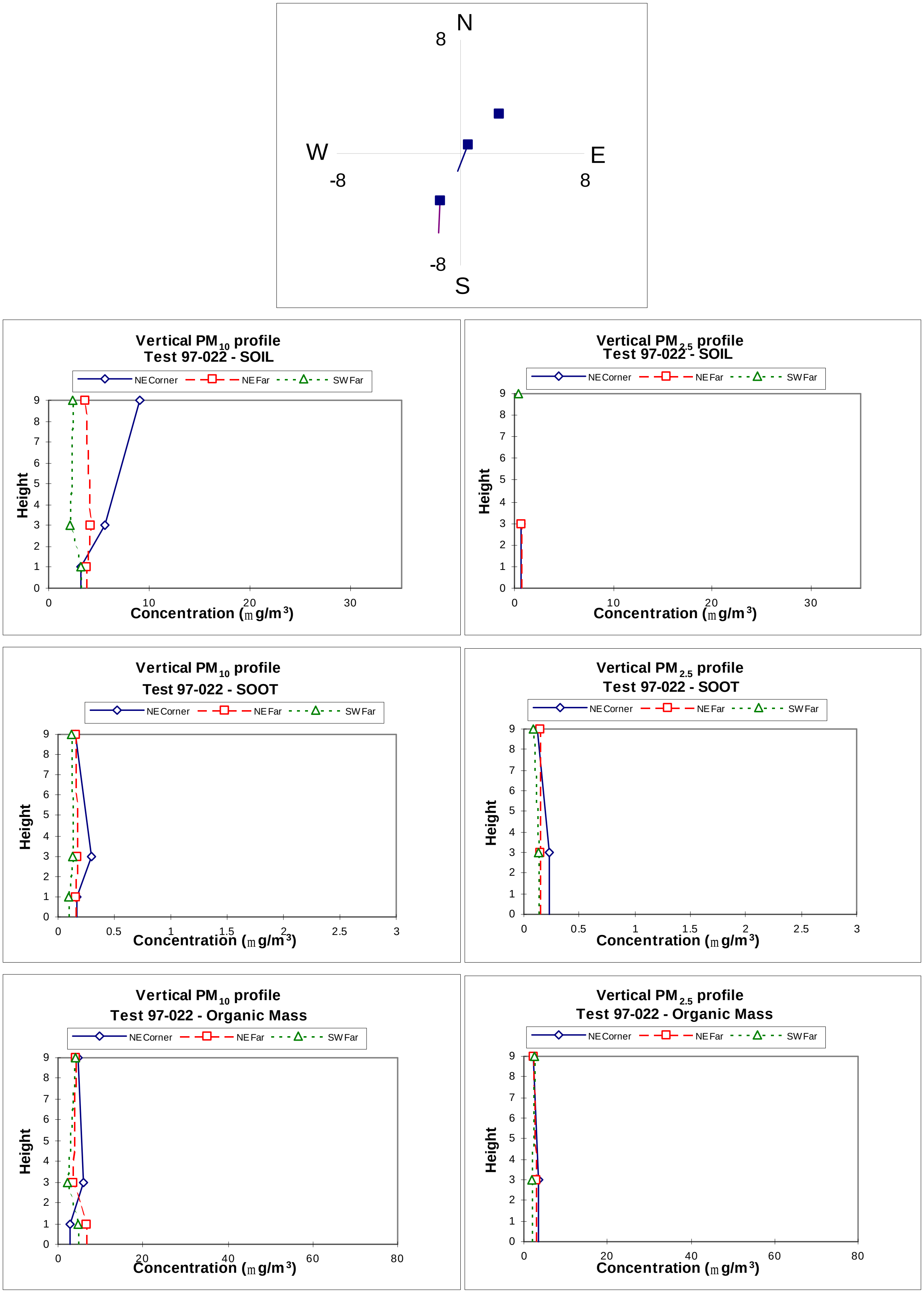


Figure 28. Vertical profiles of soil, soot, and organic mass, March 1, 1997 5:20 - 9:15 p.m.

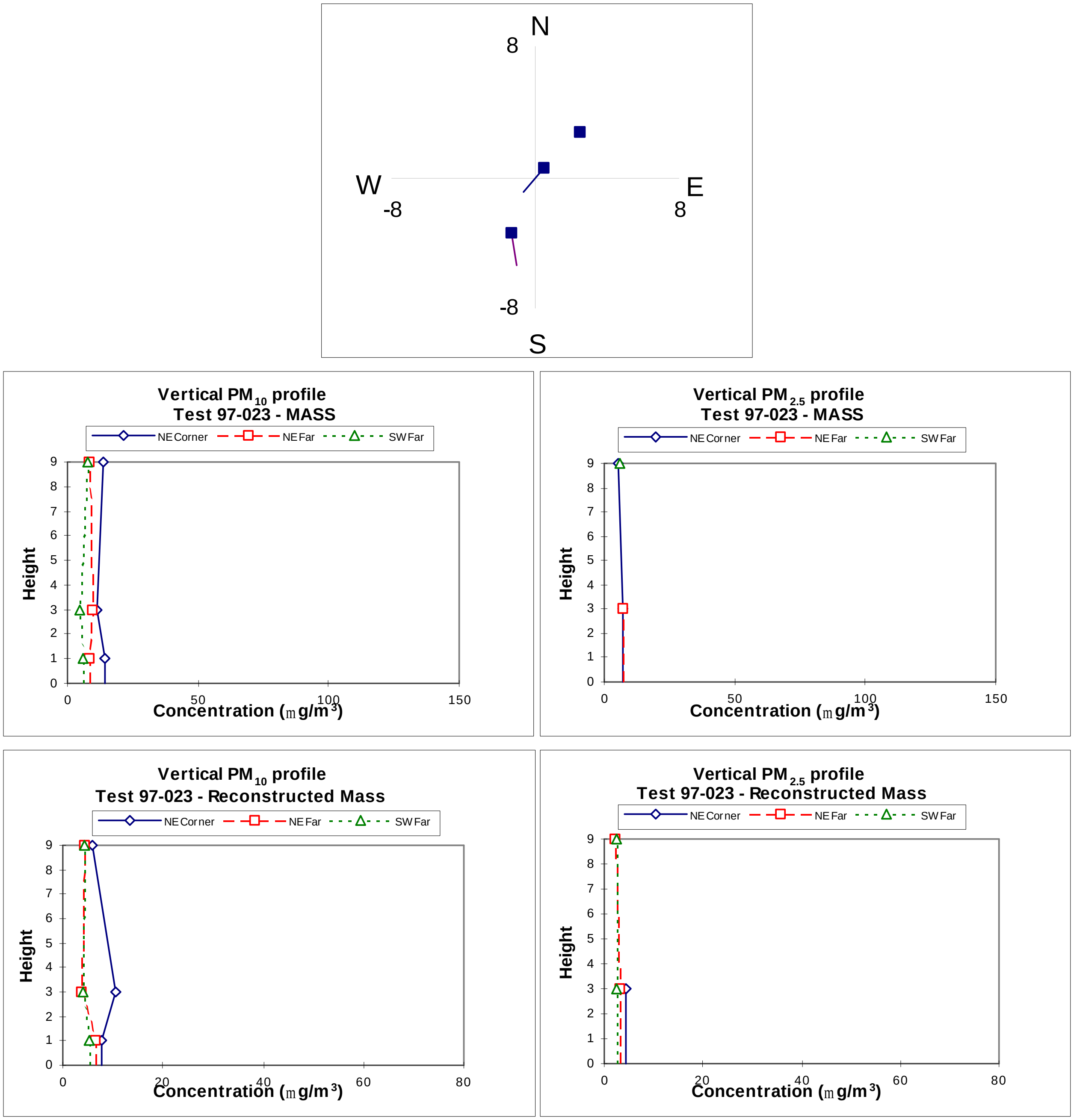


Figure 29. Wind vector plot and vertical profiles of mass and reconstructed mass, March 3, 1997 10:35 a.m. - 1:35 p.m.

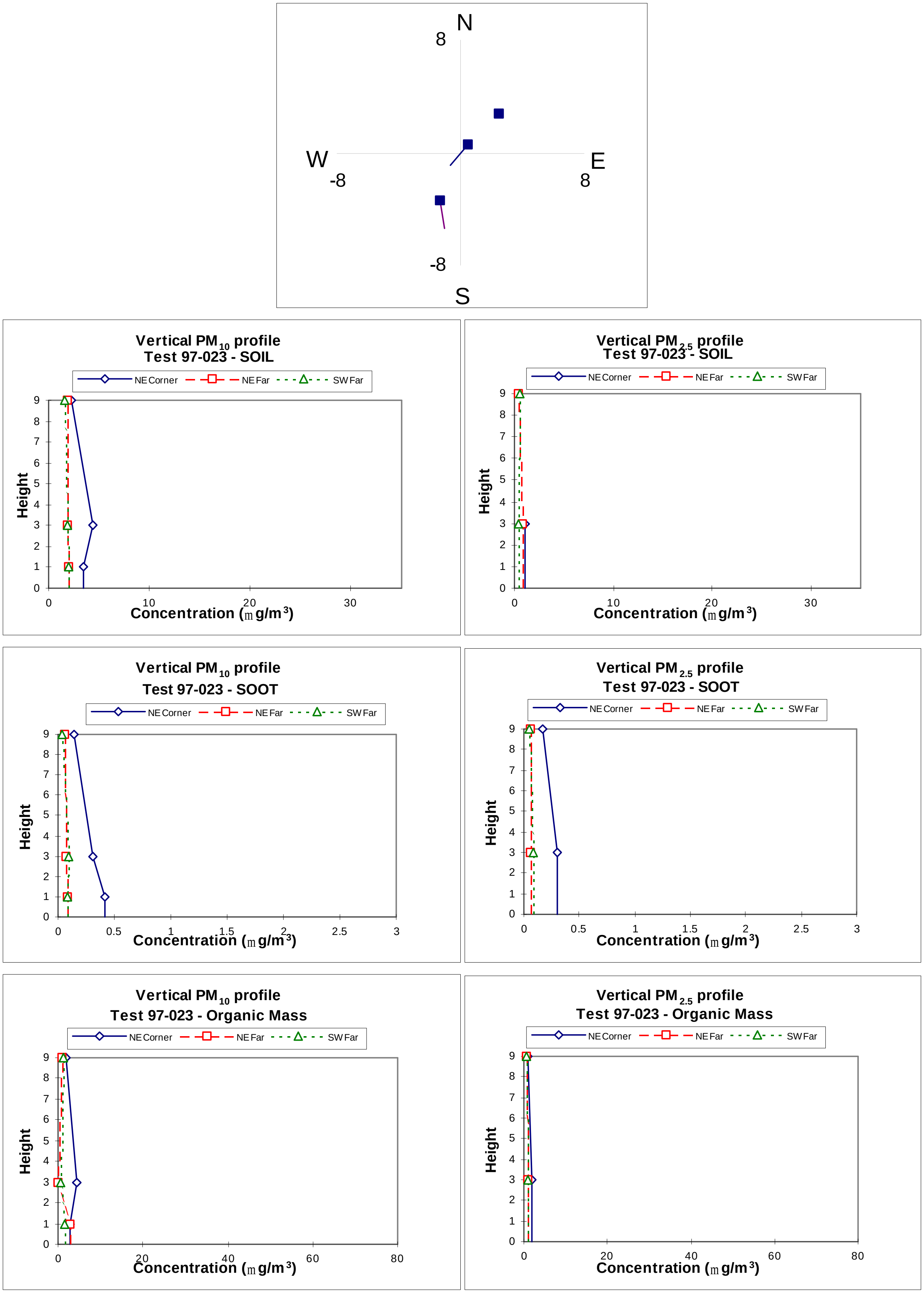


Figure 30. Vertical profiles of soil, soot, and organic mass, March 3, 1997 10:35 a.m. - 1:35 p.m.

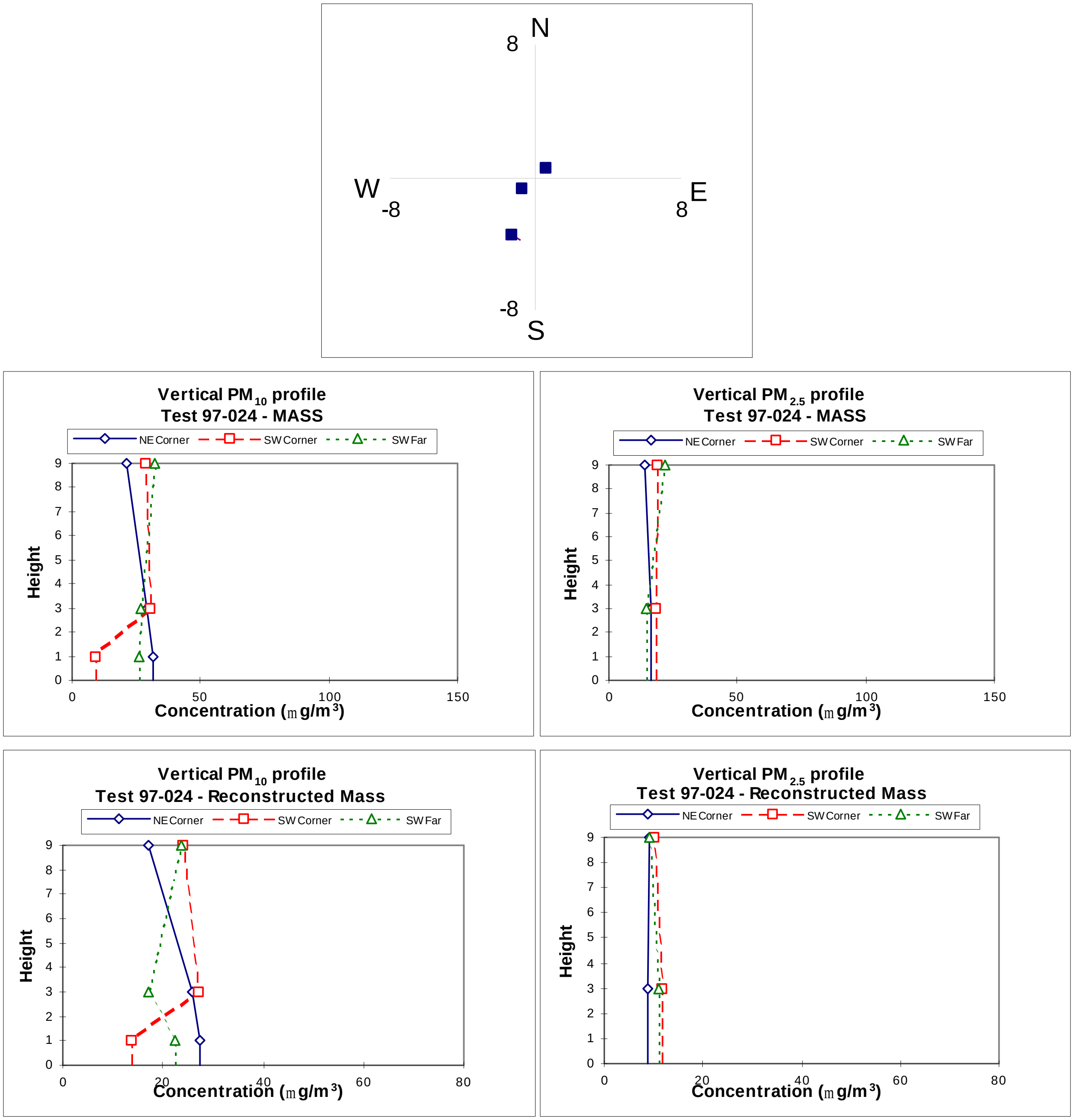


Figure 31. Wind vector plot and vertical profiles of mass and reconstructed mass, March 5, 1997 6:20 - 9:25 a.m.

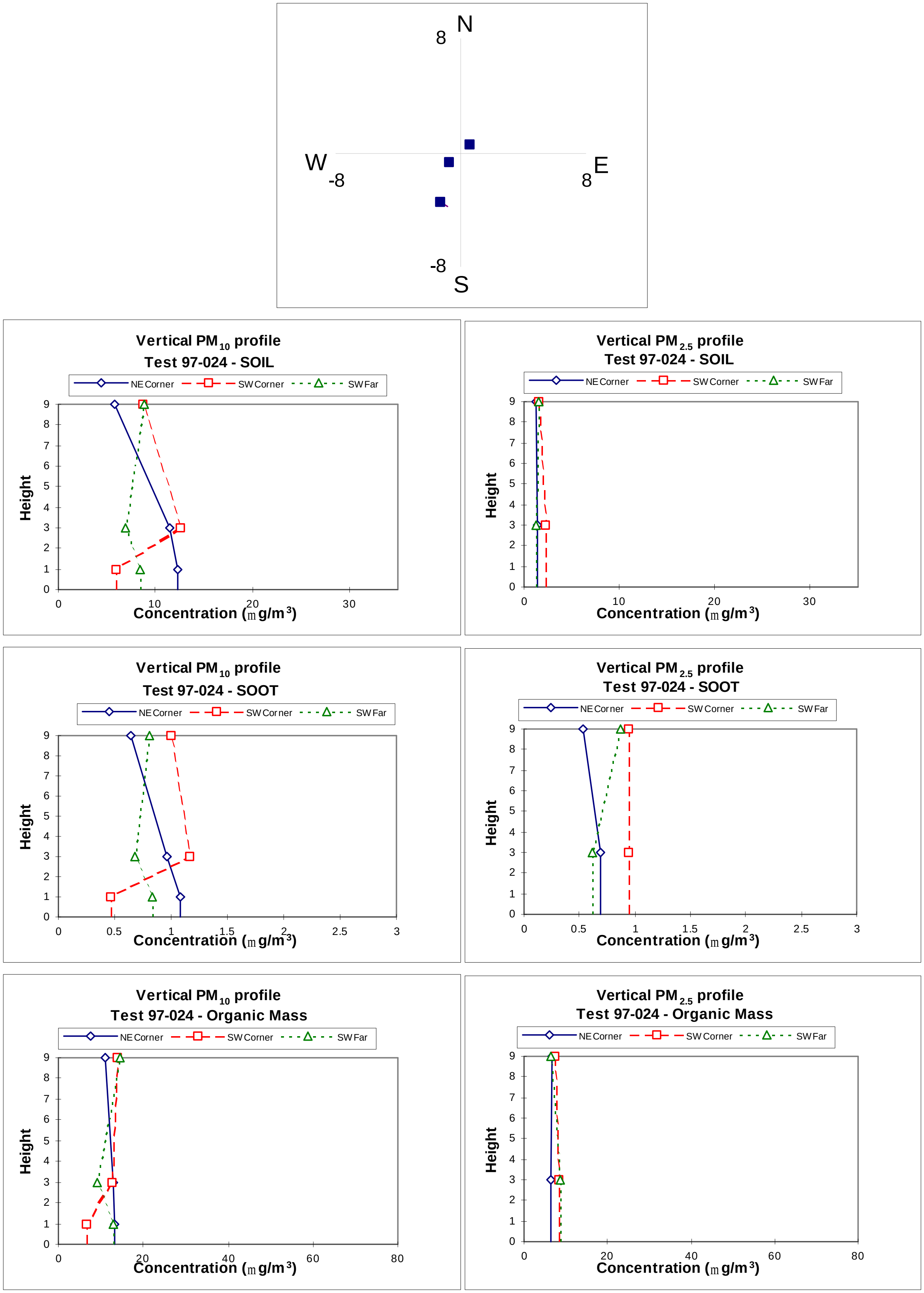


Figure 32. Vertical profiles of soil, soot, and organic mass, March 5, 1997 6:20 - 9:25 a.m.

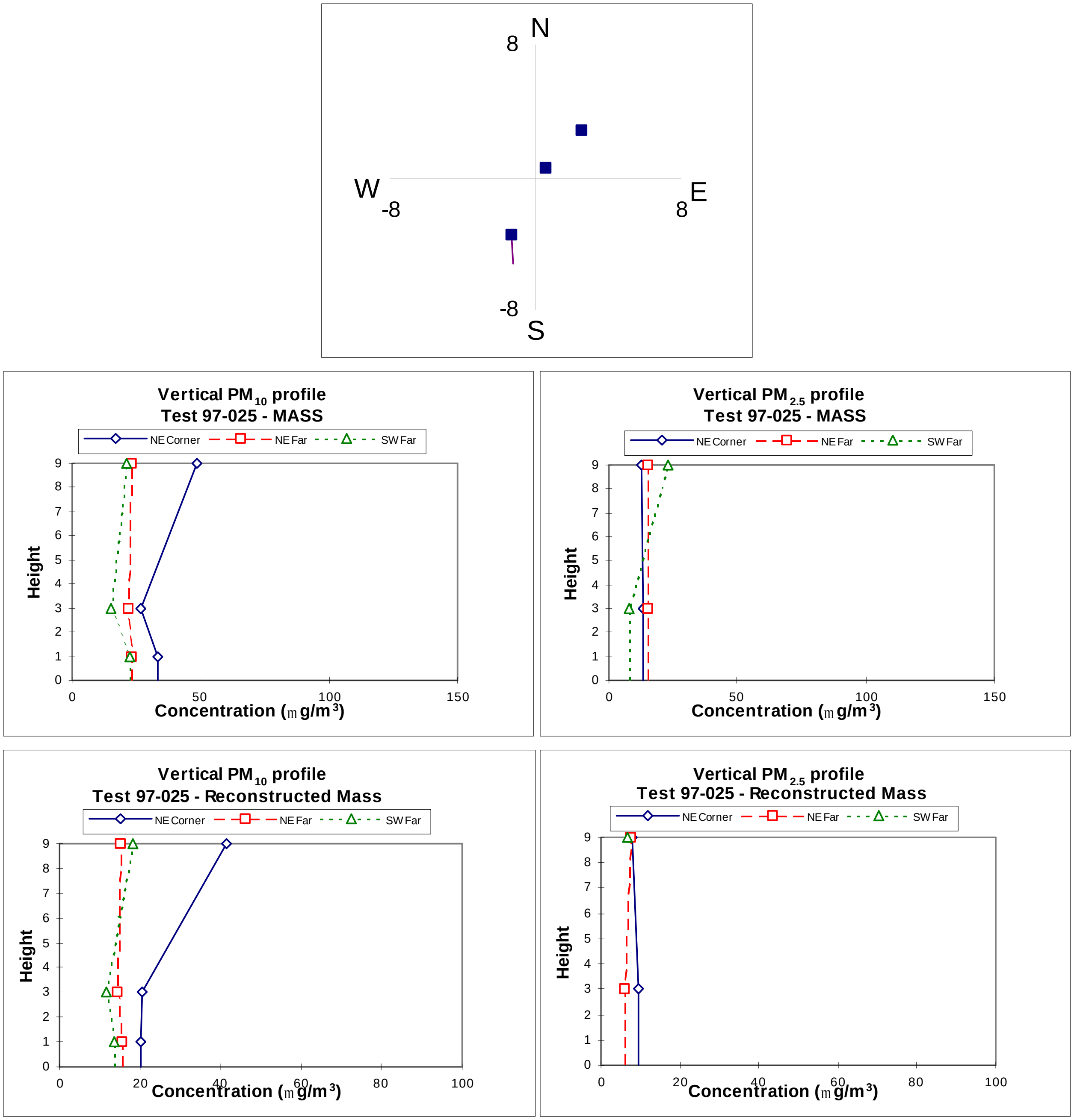


Figure 33. Wind vector plot and vertical profiles of mass and reconstructed mass, March 5, 1997 9:30 a.m. - 1:55 p.m.

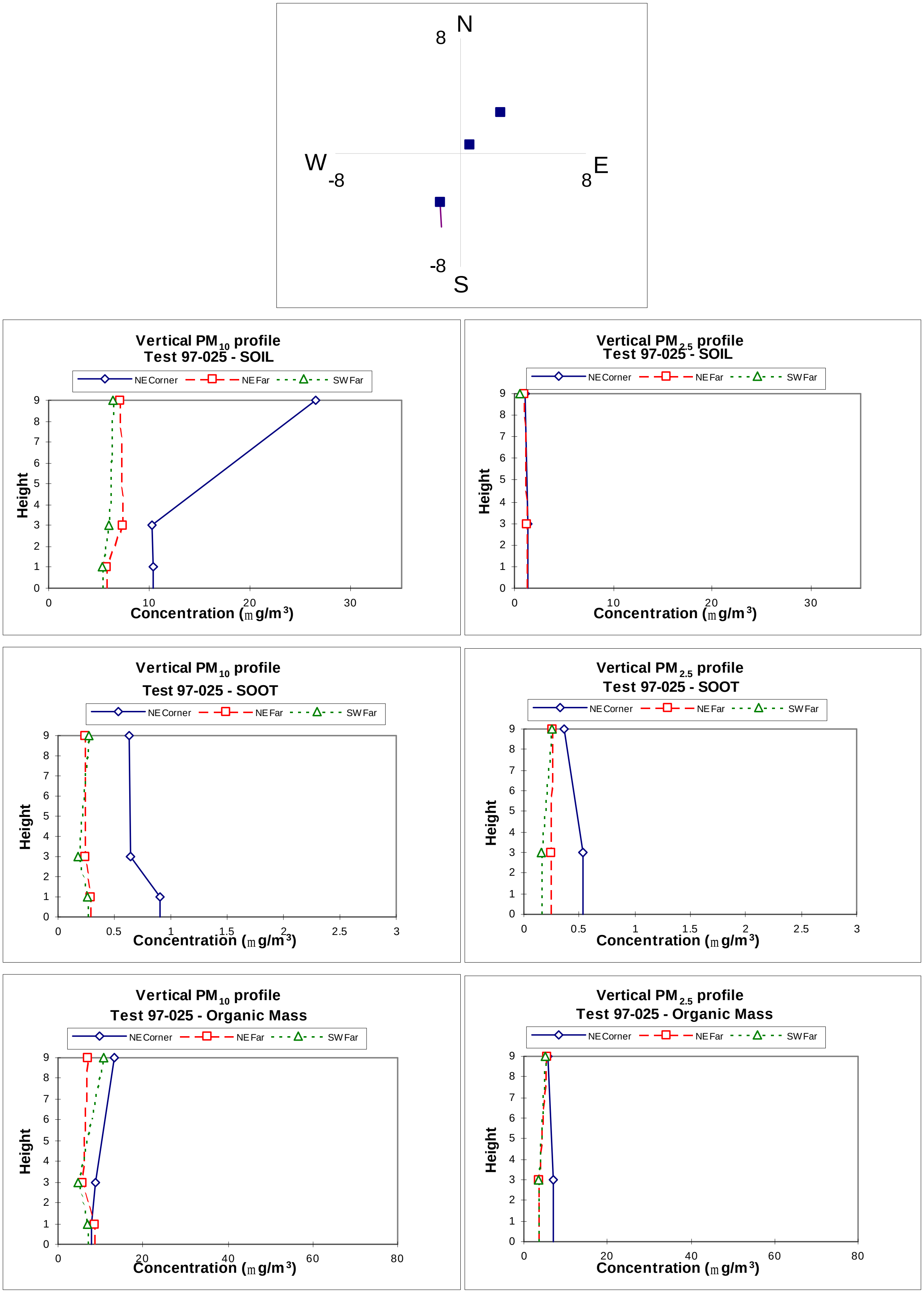


Figure 34. Vertical profiles of soil, soot, and organic mass, March 5, 1997 9:30 a.m. - 1:55 p.m.

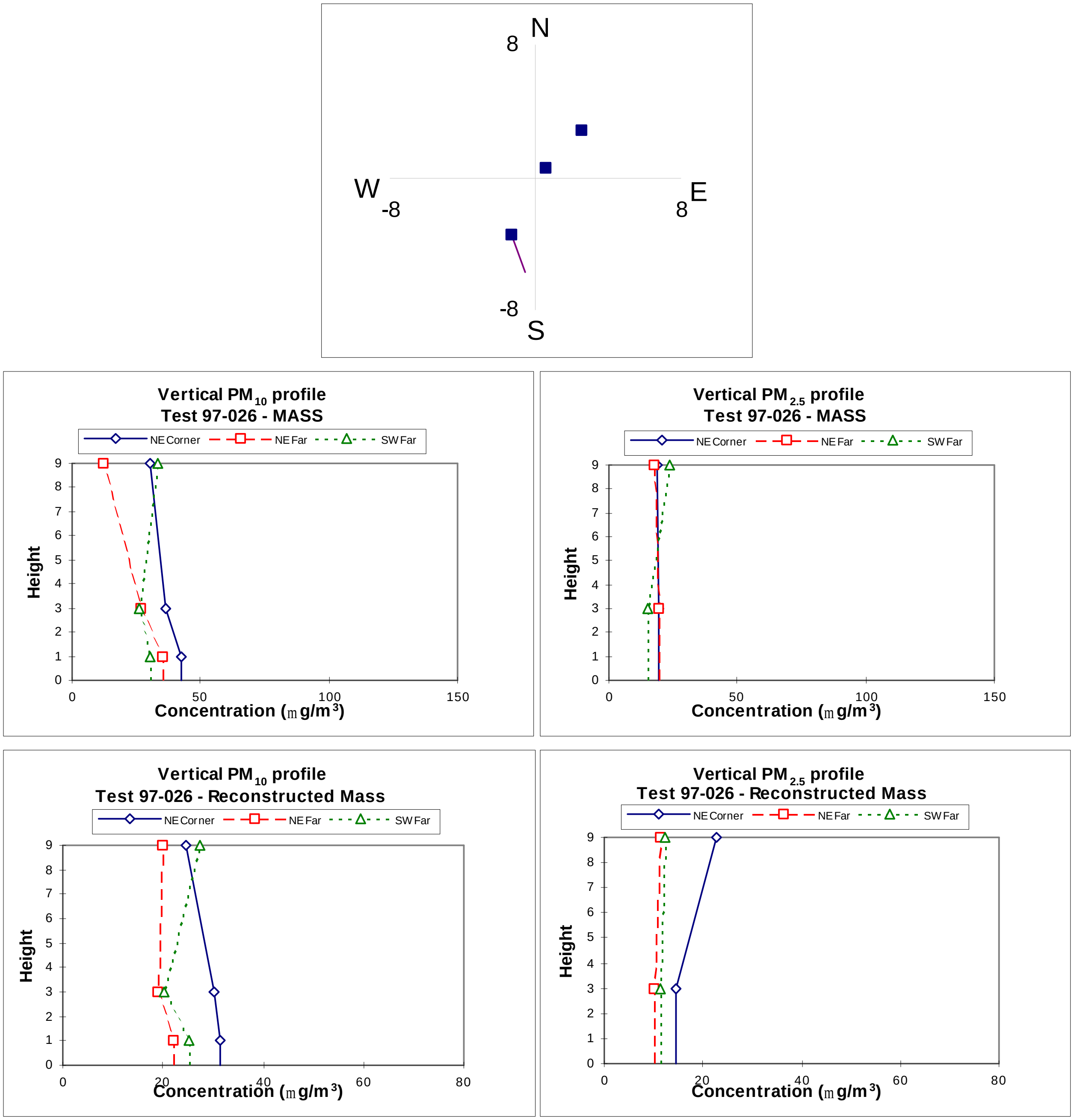


Figure 35. Wind vector plot and vertical profiles of mass and reconstructed mass, March 5, 1997 2:00 - 6:25 p.m.

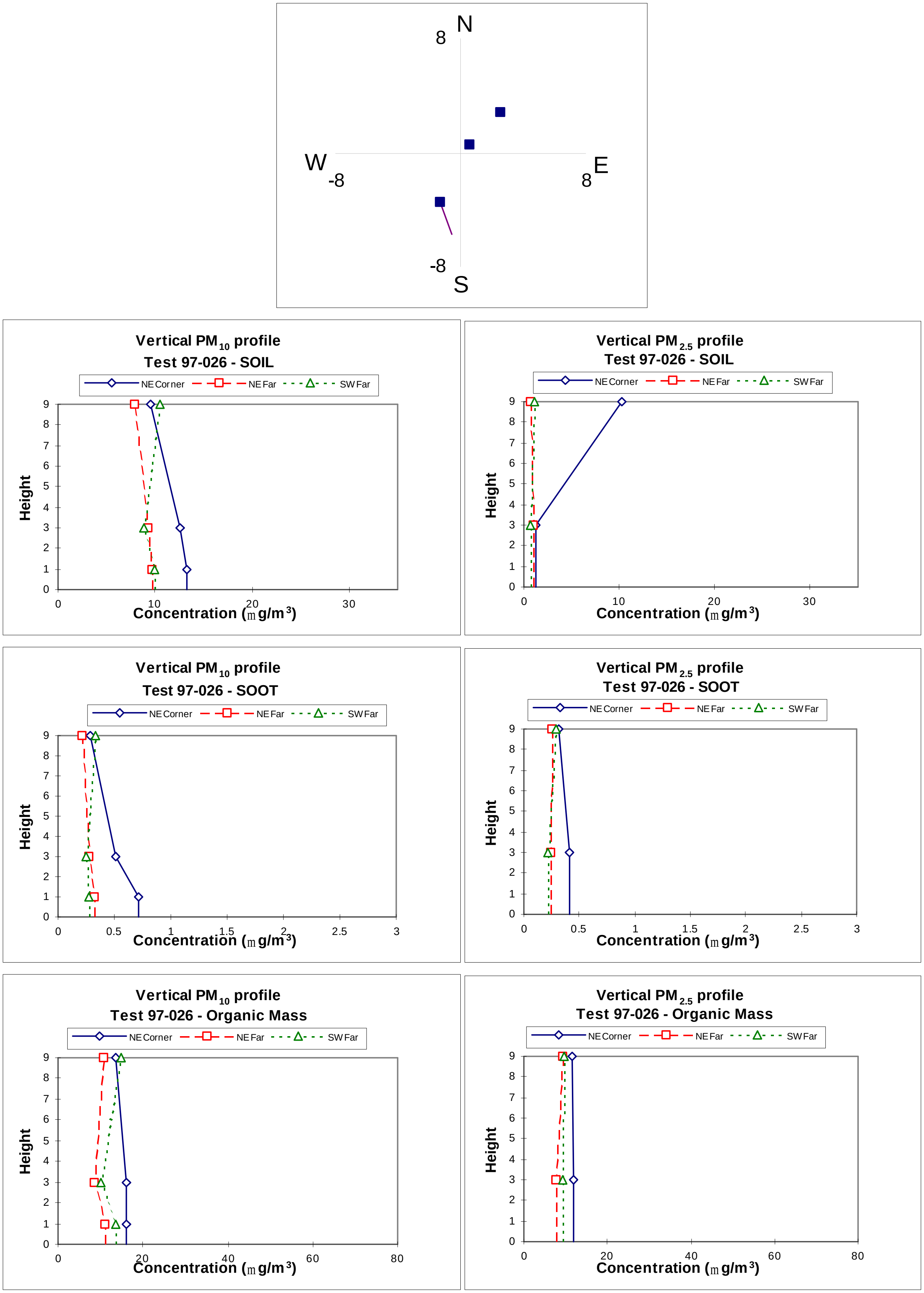


Figure 36. Vertical profiles of soil, soot, and organic mass, March 5, 1997 2:00 - 6:25 p.m.

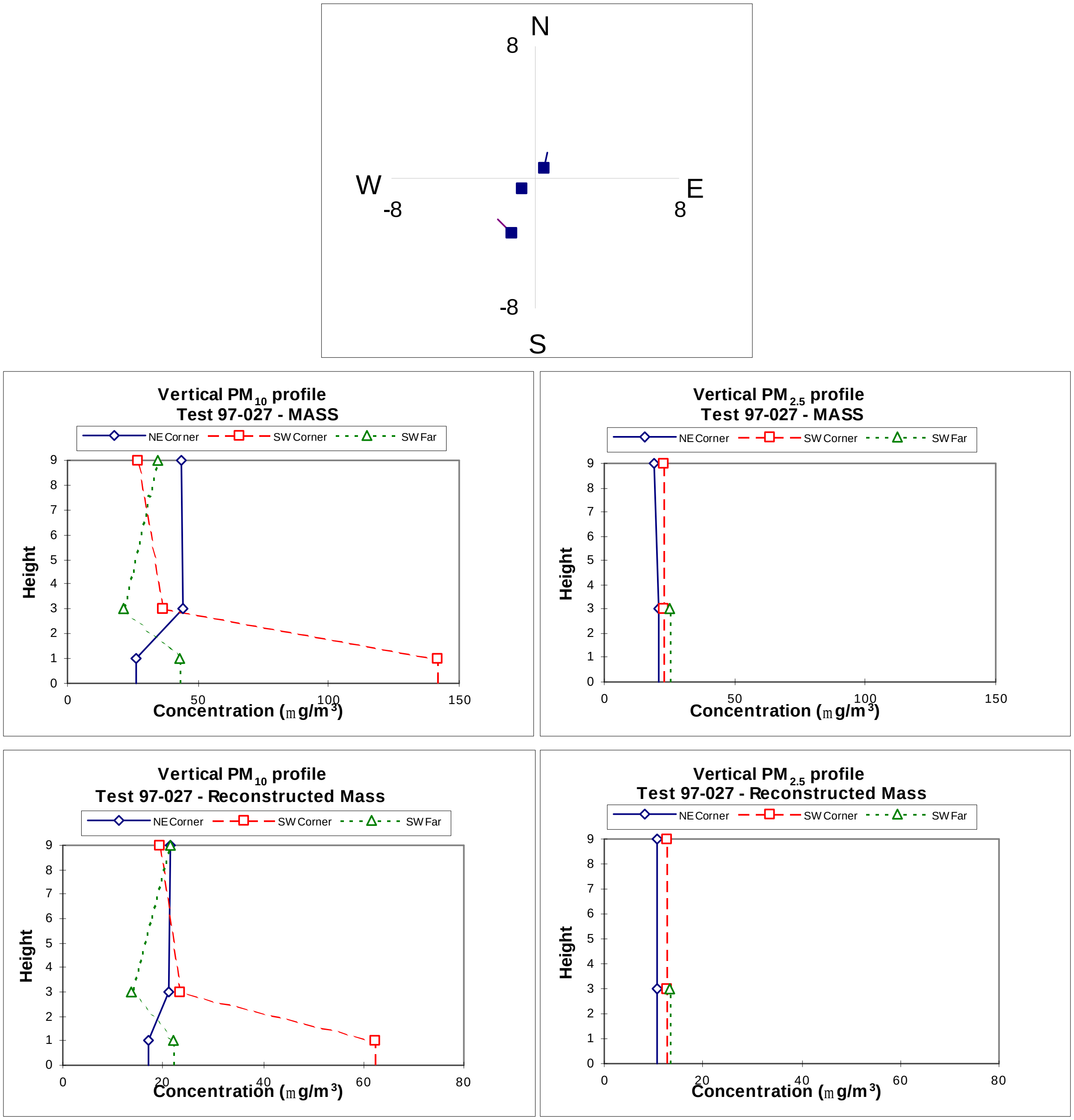


Figure 37. Wind vector plot and vertical profiles of mass and reconstructed mass, March 6, 1997 7:40 - 10:00 a.m.

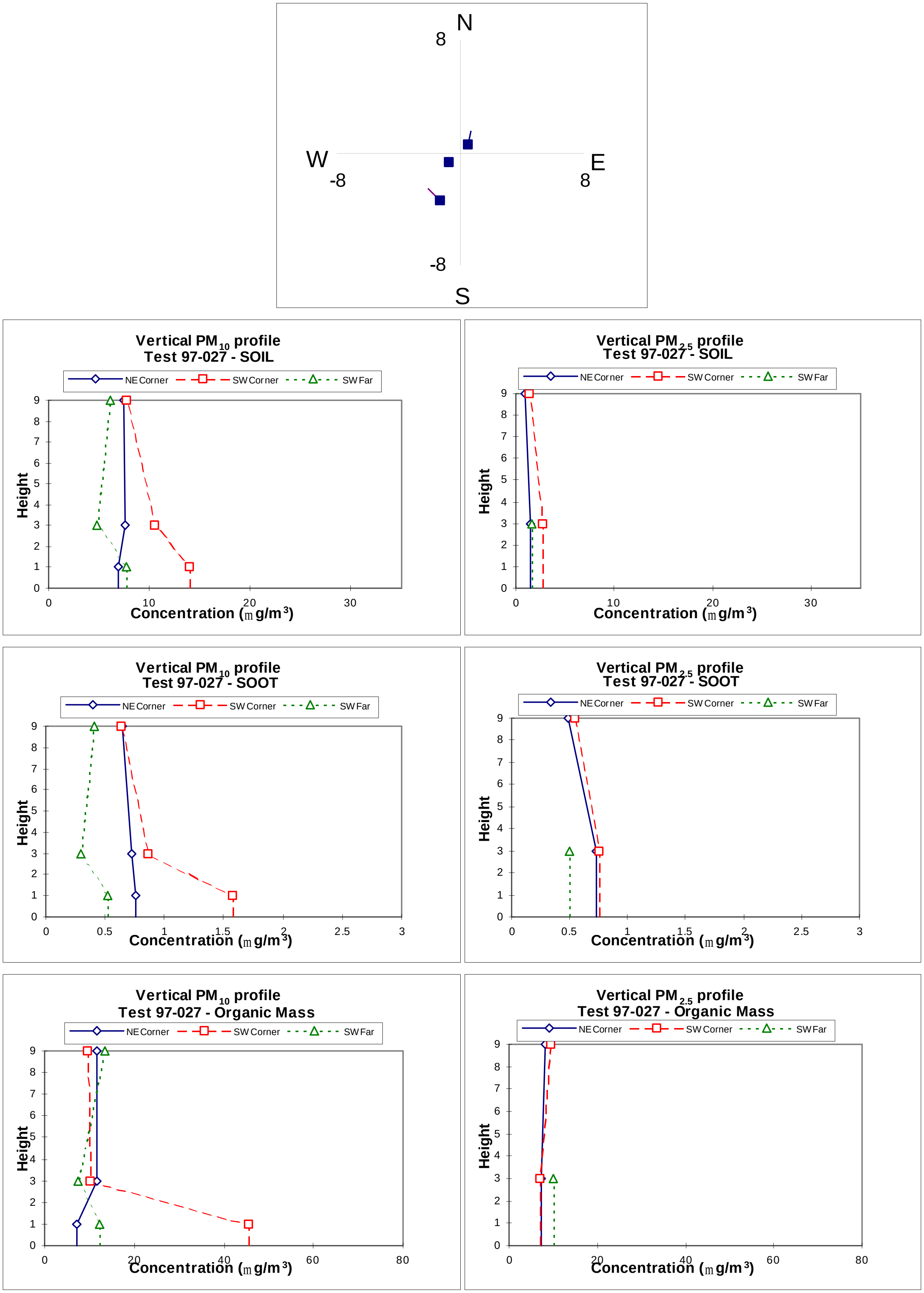


Figure 38. Vertical profiles of soil, soot, and organic mass, March 6, 1997 7:40 - 10:00 a.m.

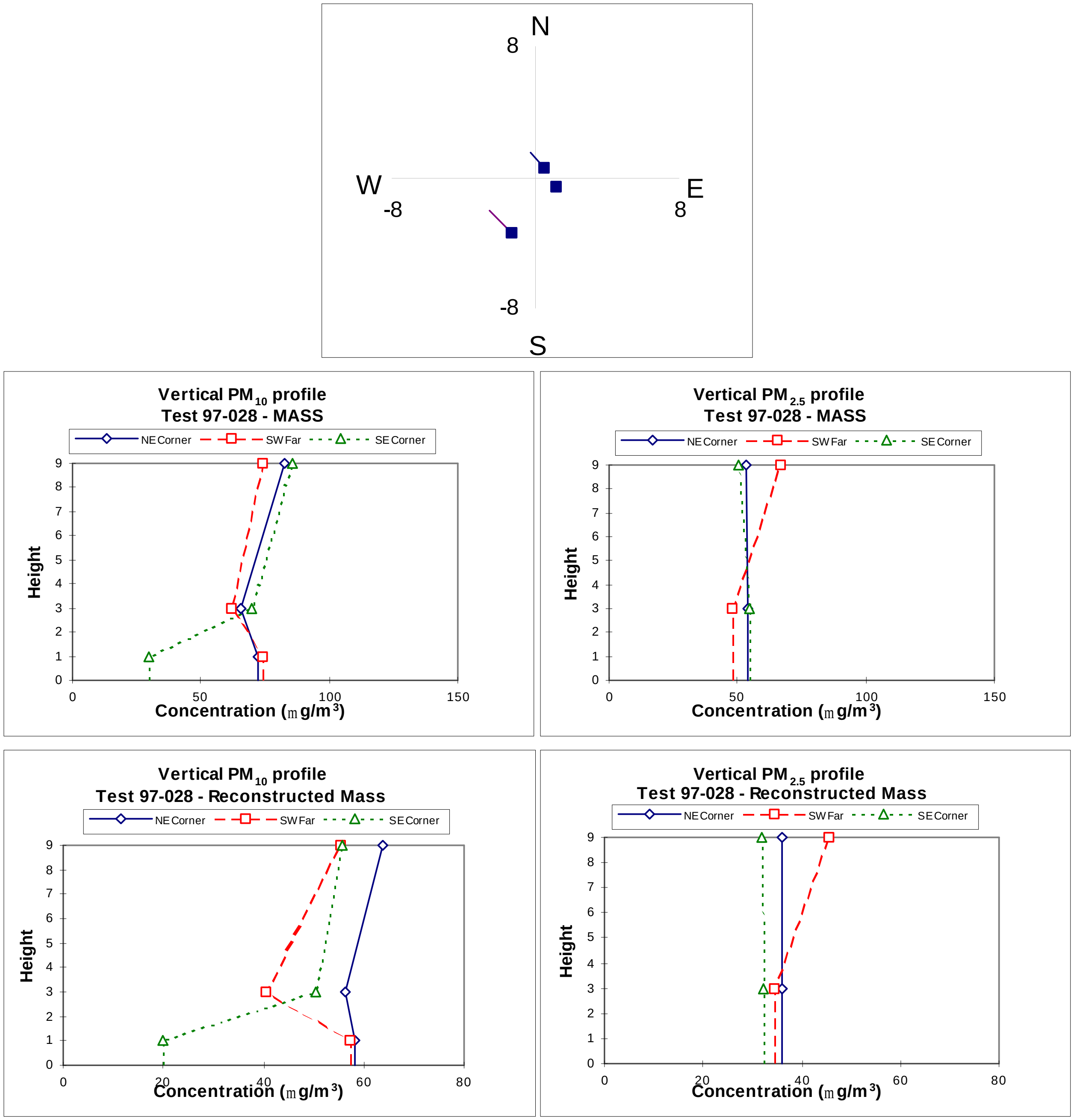


Figure 39. Wind vector plot and vertical profiles of mass and reconstructed mass, March 6, 1997 4:55 - 6:40 p.m.

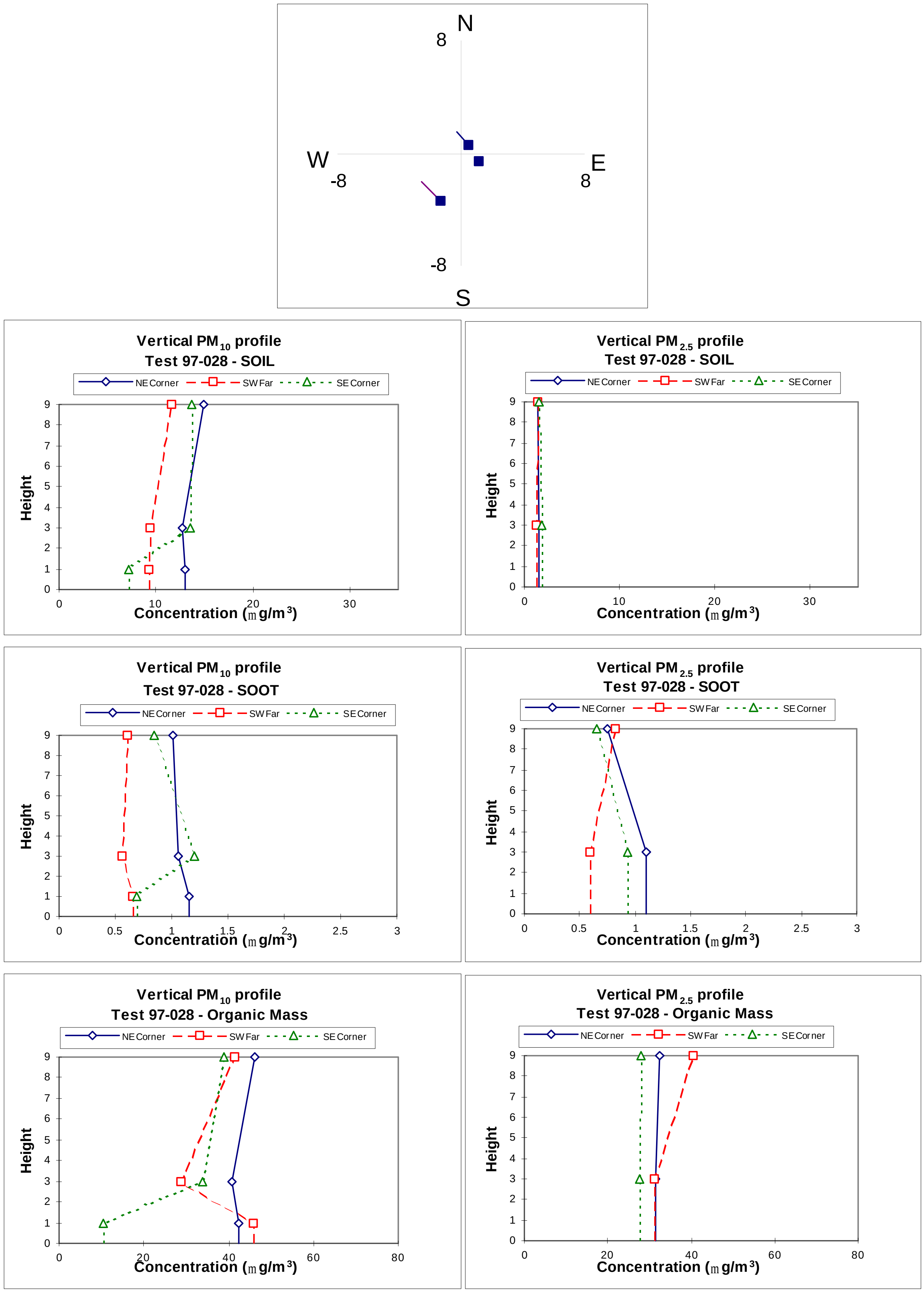


Figure 40. Vertical profiles of soil, soot, and organic mass, March 6, 1997 4:55 - 6:40 p.m.

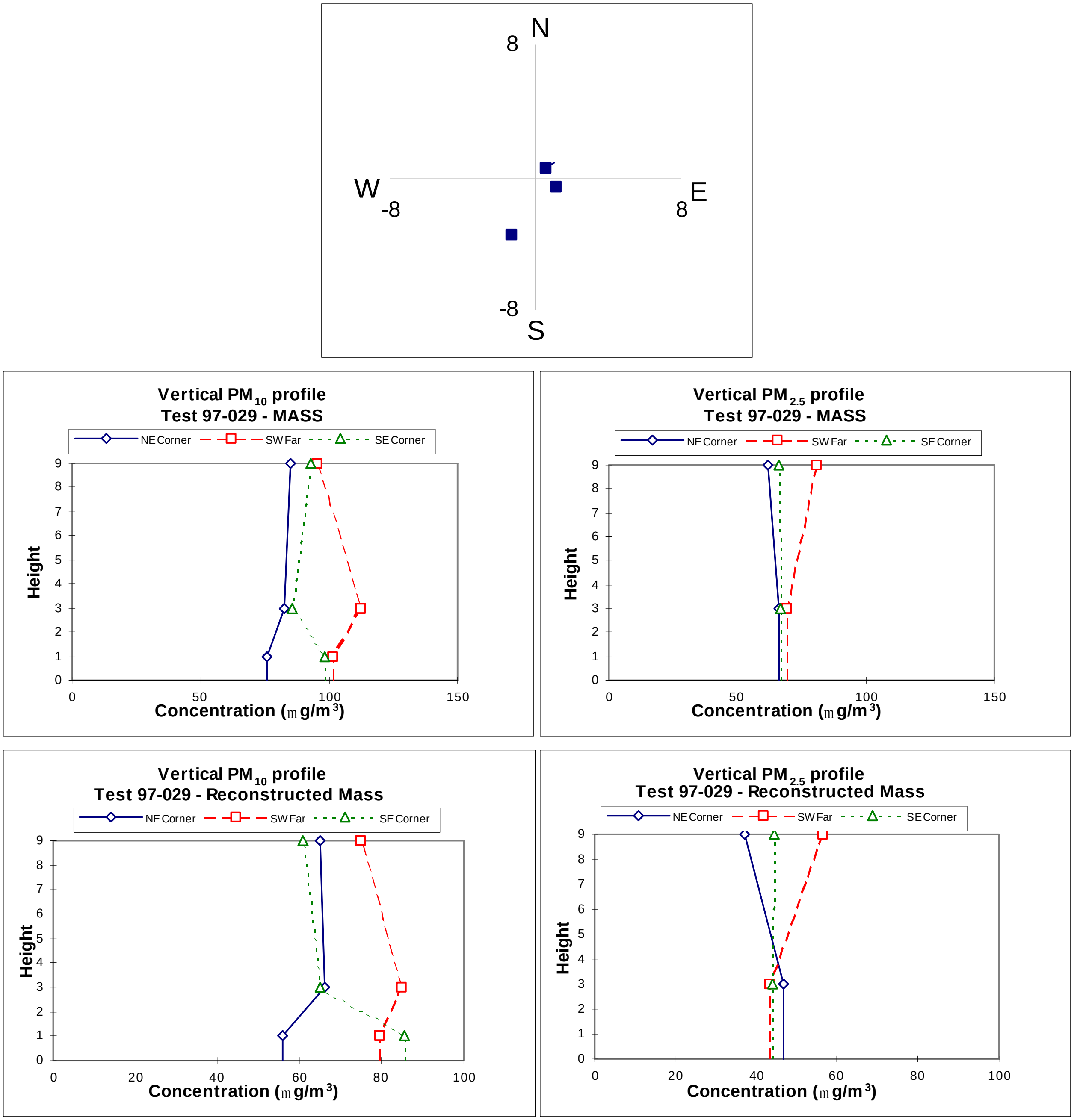


Figure 41. Wind vector plot and vertical profiles of mass and reconstructed mass, March 6, 1997 6:45 - 11:15 p.m.

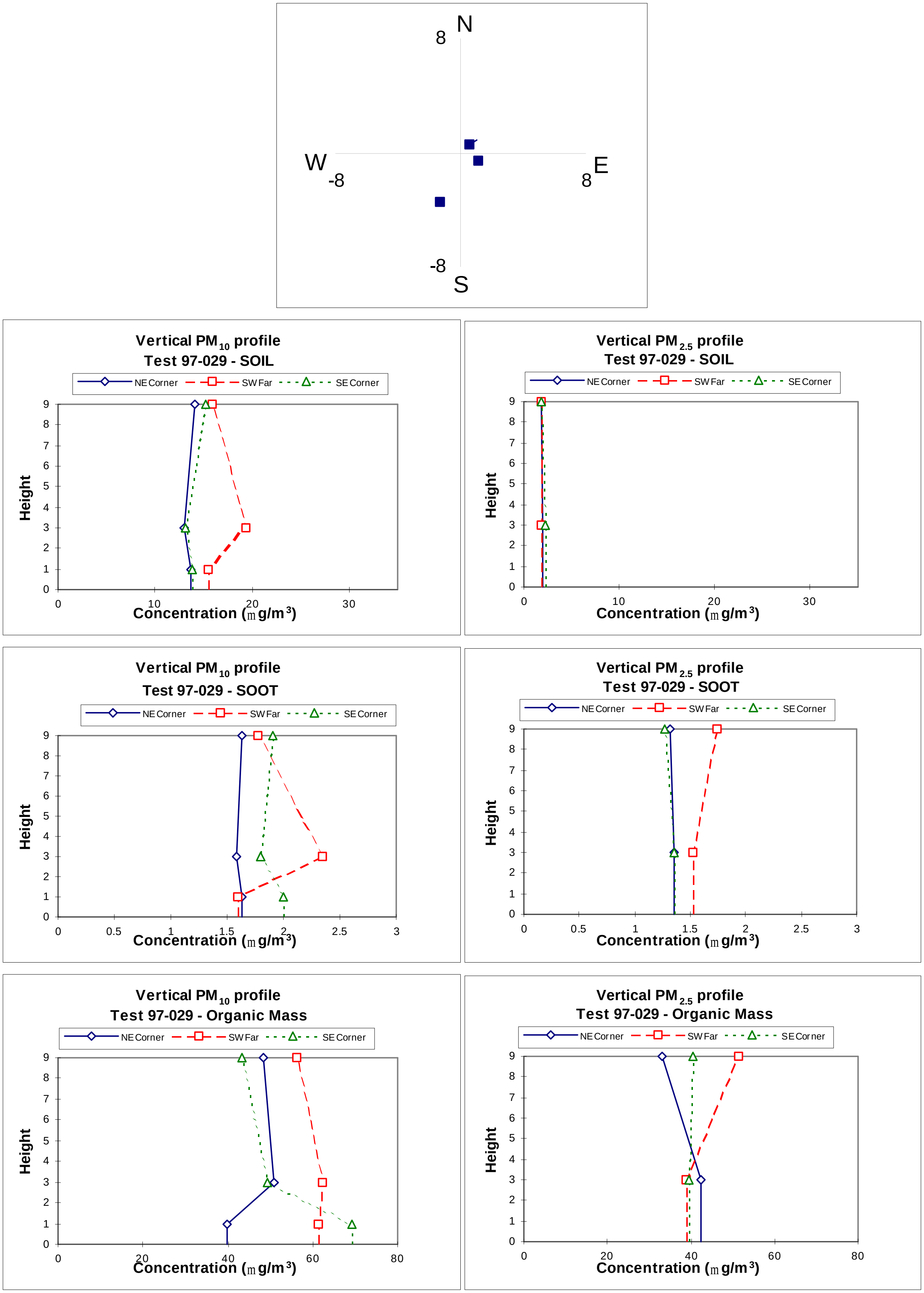


Figure 42. Vertical profiles of soil, soot, and organic mass, March 6, 1997 6:45 - 11:15 p.m.

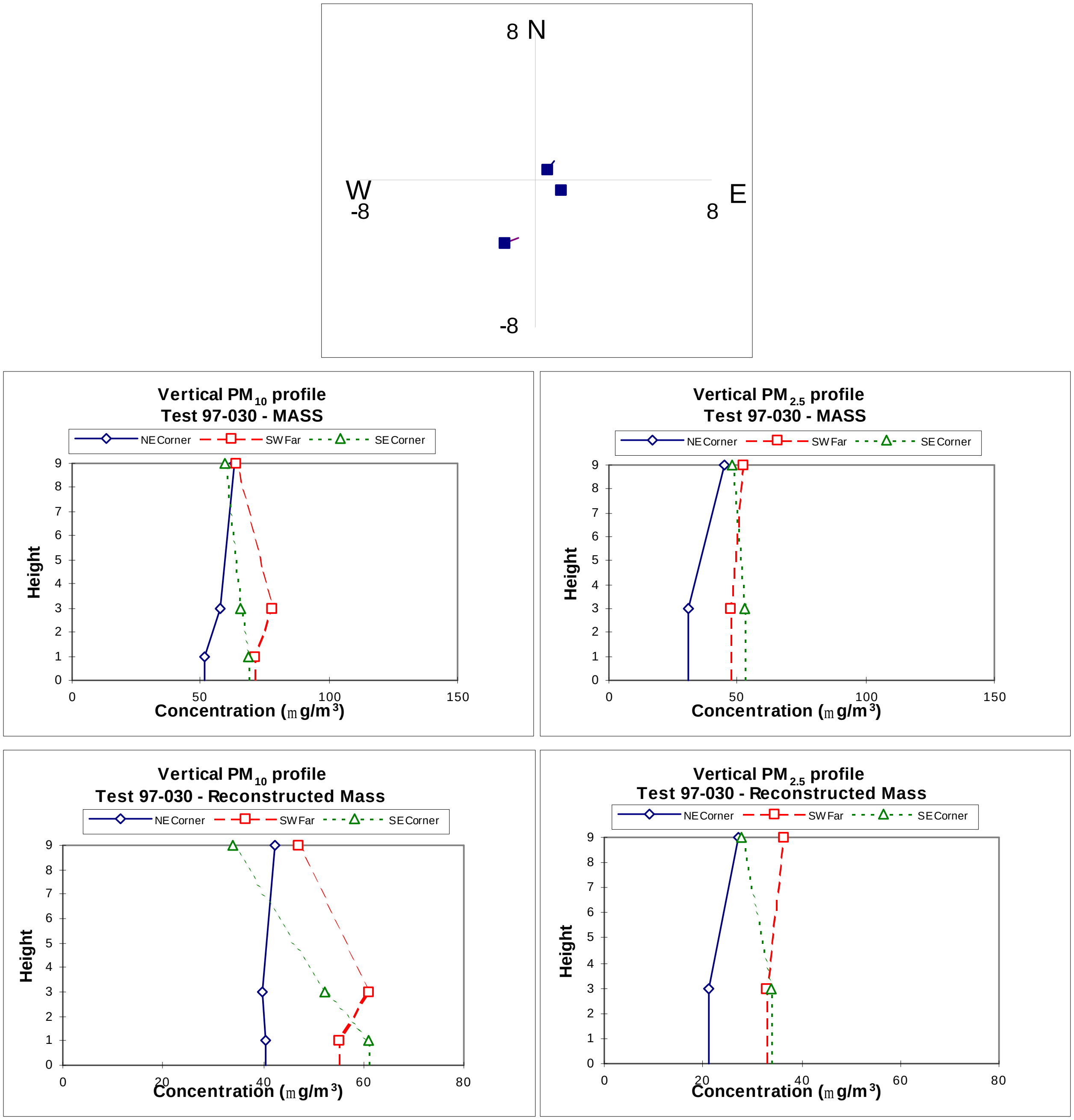


Figure 43. Wind vector plot and vertical profiles of mass and reconstructed mass, March 6, 1997 11:20 p.m. - March 7, 1997 4:00 a.m.

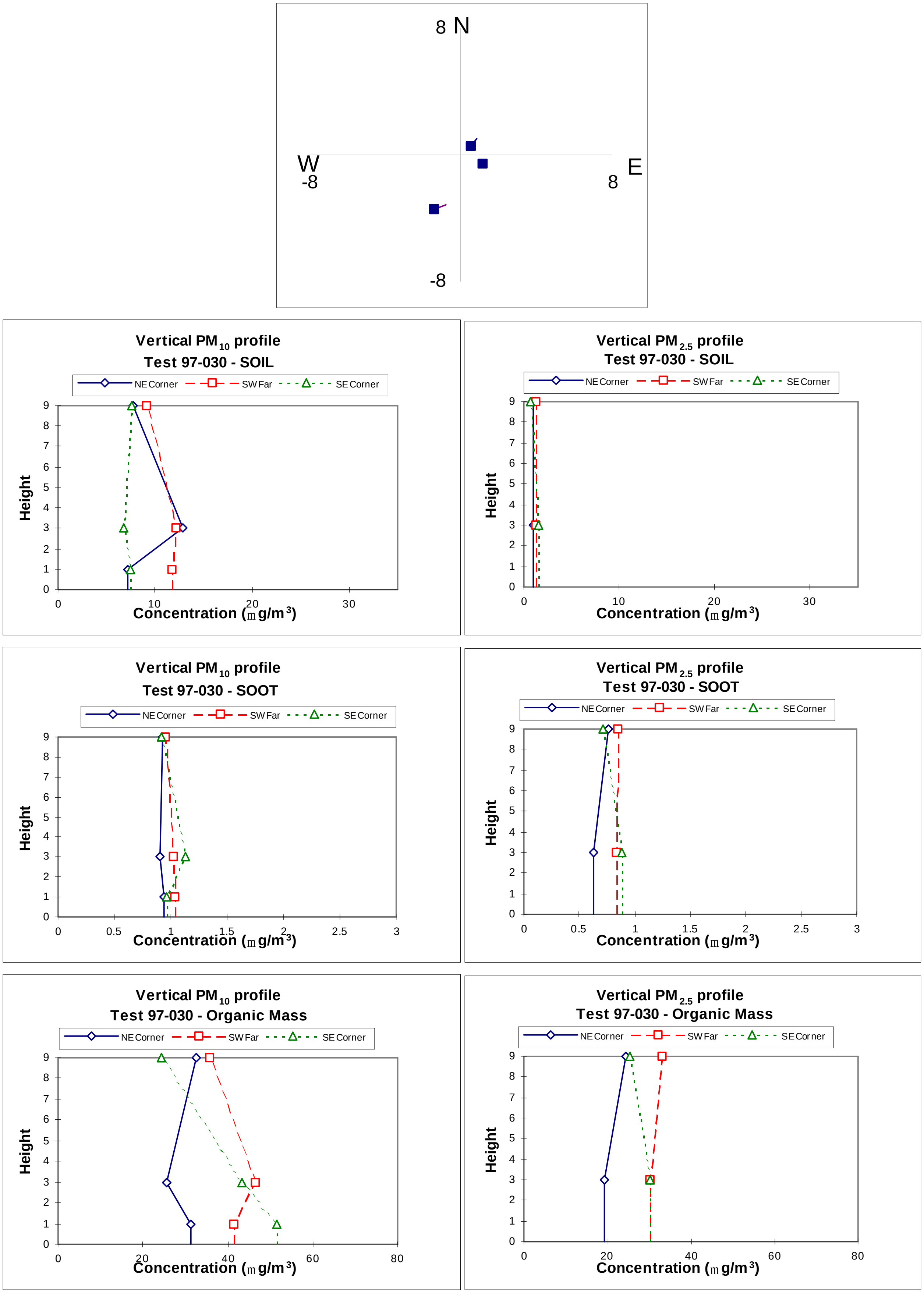


Figure 44. Vertical profiles of soil, soot, and organic mass, March 6, 1997 11:20 p.m. - March 7, 1997 4:00 a.m.

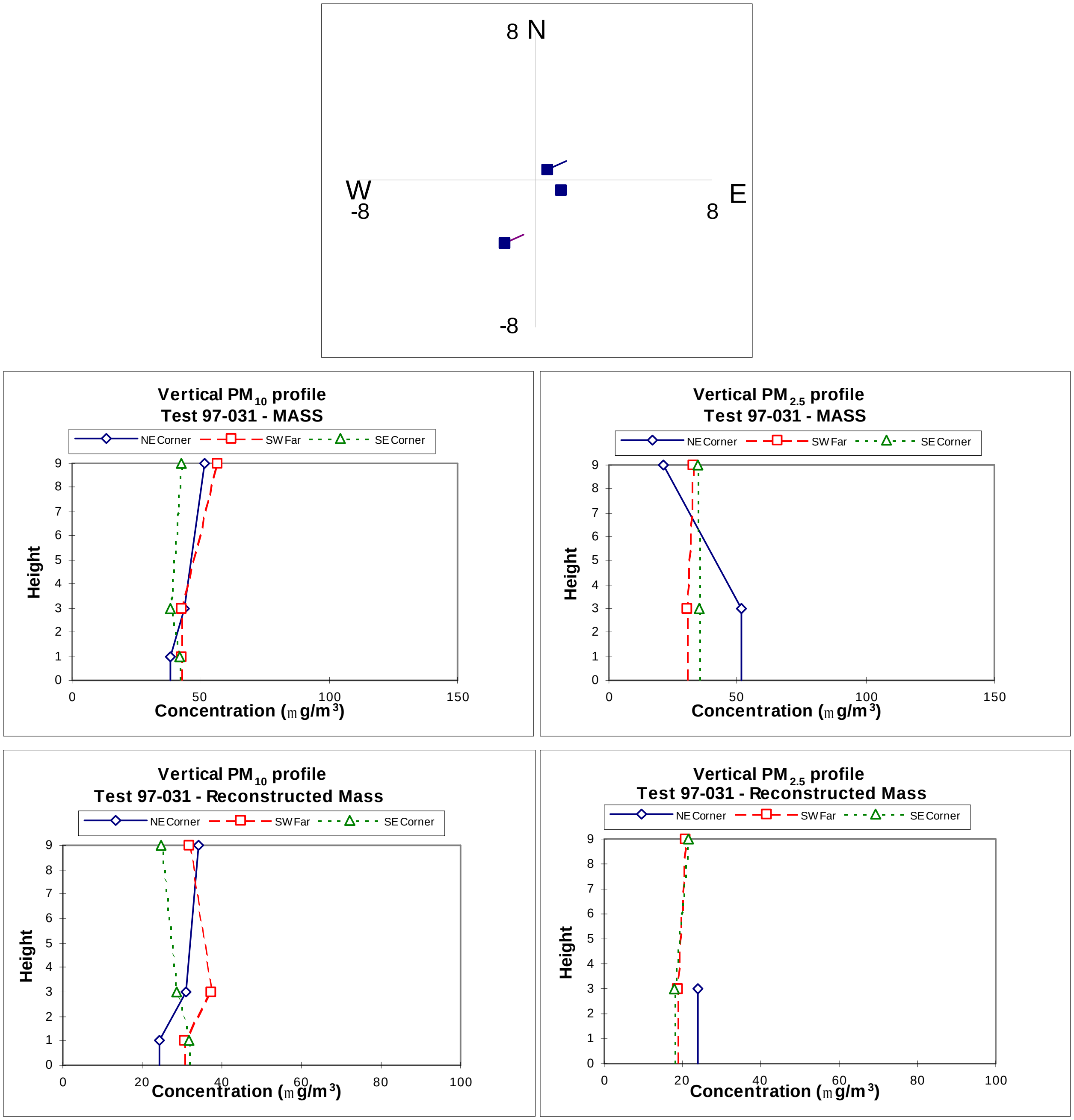


Figure 45. Wind vector plot and vertical profiles of mass and reconstructed mass, March 7, 1997 6:40 - 9:25 a.m.

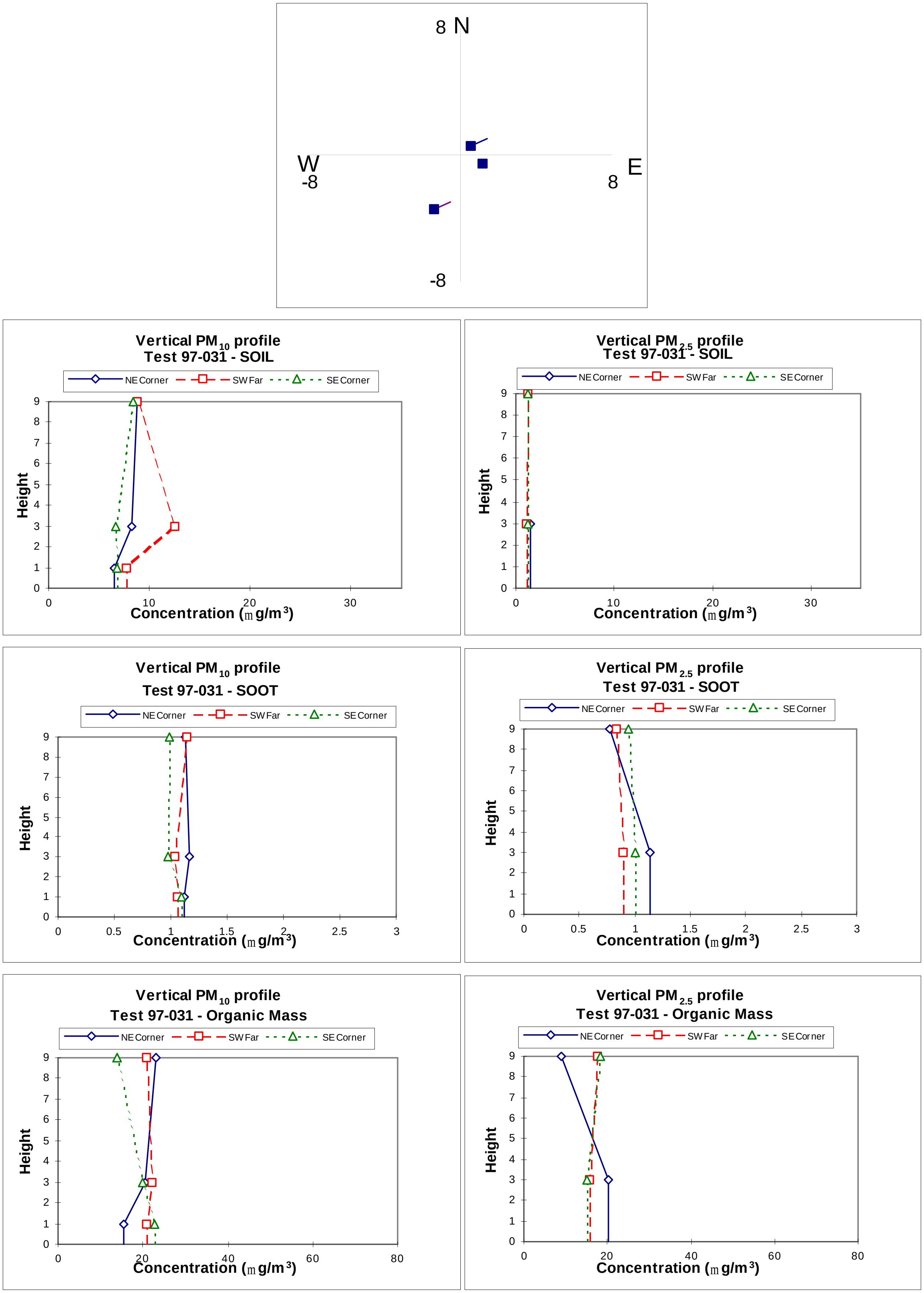


Figure 46. Vertical profiles of soil, soot, and organic mass, March 7, 1997 6:40 - 9:25 a.m.